EVALUATION OF PREDATORY SPIDERS AS BIOLOGICAL CONTROL AGENTS OF CITRUS LEAFMINER, *PHYLLOCNISTIS CITRELLA*, IN LIME ORCHARDS AT HOMESTEAD, FLORIDA

By

DIVINA MEDINA AMALIN

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1999

Copyright 1999

by

Divina Medina Amalan

This effort is dedicated to my parents – Pablo Amalin and Marcelina Medina

ACKNOWLEDGMENTS

This research would have not been completed without the support of several people and institutions Special recognition is extended to Dr Jorge E Peña, for his support and guidance. He supervised this research critically and helpfully

I also thank the other members of my supervisory committee. Dr Robert McSorley was supportive in all matters. He helped me conceptualize some of the experiments. Dr Jonathan Reiskind, Dr Harold Browning, and Dr Jonathan Crane provided valuable suggestions on some of the experiments

Special thanks are extended to Dr G B Edwards for checking spider identification and determining a few difficult species, Dr Kenneth Portier for statistical advise, Mr Alberto Barrion for his comments on the spider identification key, and Dr Ru Nguyen and Mr Larry Keal for the supply of citrus leafminer adults. I also would like to thank Ian Jackson and Dr J P Michaud of CREC Lake Alfred for helping me with the video taping and Dr David Moraga and his staff who provided hands-on training with electrophoresis Thanks also go to Dr Simon Yu, Dr Pauline Lawrence, and their staff for allowing me to use their laboratory equipment and to Dr Dennis Gray and Dr Jayasankar for allowing me to use their equipment for scanning the electrophoretic gel. I also would like to thank Dr Richard Lutz for carefully editing this dissertation

Thanks also go to the faculty and staff of the Department of Entomology and Nematology for their support. Special thanks go to Dr Charlie Tarjan, Dr Grover Smart, Debbie Hall, Myrna Litchfield, Nancy Sanders, and Steve Lasley My appreciation goes to all the students in the department who shared with me the good times and the hard times of earning this degree, most especially to Hugo, Maria, Bettina, Andy, Annie, Joan, Loyce, Juan Villanueva, Juan Alvarez, Yasmin, Alonzo, Denise, and Raul

My deepest gratitude goes to the entire faculty and staff at the Tropical Research and Education Center especially to Dr Waldy Klassen. Special thanks go to Rita, Adrian, Teresa, Michelle, Mo Ivan, Pam. Angel, Arne, Bryan, Dr Zhentu, and Dr Ramos for their moral support My sincere thanks to Alegria who helped in the field collections and greenhouse maintenance Thanks alsogo to Dr Baranowski and Holly Glenn for letting me use the time lapse video recorder Special thanks go to Dr Witjaksono for critically and helpfully formatting this dissertation and for help with photomicrography and to his wife Nia. Thanks also go to the adopted "TRECies" Josep Hilmig, Isabel, Carmen, Marcela. Abdel and family Levi and family, Sara and family, and the former "TRECies", Tony, Manolo Jay and Siva for their company and unending support My thanks go to the students at TREC. Umpika, Darda, Maritza, Hilary Wendy, and Julieta for the moral support.

I also thank the Filipino community (Gainesville chapter) Special thanks go to Shiela and Jun Gomez, Bob and Para Kemerait, Camille and Gino Ables, Tess and Toto Oña, Odi, Gigi, and Cecil My thanks also go to Zenaida, Octavio, Zeynel, and Noeng for the nice company

I am grateful to my family for their love and for understanding why I am away from them. Special thanks go to Kuya Scott and Ate Mila for considering me part of their family and for their love and care.

To all of you and to those that I have failed to mention, your help and support made this piece of work a reality

TABLE OF CONTENTS

page

ACKNOWLEDGMENTS iv

LIST OF TABLES x

LIST OF FIGURES xii

ABSTRACT xvi

CHAPTER 1 INTRODUCTION 1
- Baseline Information about the Test Organisms 3
  - Citrus Leafminer 3
    - Biology of the Citrus Leafminer 3
    - Control Measures 7
  - Spiders 11
- Research Goals 16

CHAPTER 2 SURVEY OF SPIDERS OCCURRING IN LIME GROVES IN HOMESTEAD, SOUTH DADE COUNTY FLORIDA 18
- Introduction 18
- Materials and Methods 20
  - Preliminary Survey of Predatory Arthropods 20
  - Comparison of Three Different Sampling Techniques 21
  - Spiders in Sprayed and Nonsprayed Orchard 22
- Results and Discussion 23
  - Preliminary Survey of Predatory Arthropods 23
  - Comparison of Sampling Methods 31
  - Spiders in Sprayed and Nonsprayed Orchards 35

CHAPTER 3 PREDATION BY THREE SPECIES OF SAC SPIDERS ON CITRUS LEAFMINER, *PHYLLOCNISTIS CITRELLA* (LEPIDOPTERA GRACILLARIIDAE) 42
- Introduction 42
- Materials and Methods 43
  - Laboratory Feeding Test 43
  - Feeding Efficacy Test 45
  - Gut Content Analysis 49
- Results and Discussion 50

Feeding Test 50
Feeding Efficiency Test 51
Gut Content Analysis through Electrophoresis 60

CHAPTER 4 PREDATORY BEHAVIOR OF THREE SPECIES OF HUNTING SPIDERS ATTACKING CITRUS LEAFMINER 64
Introduction 64
Materials and Methods 66
Time of Feeding Activity 66
Predatory Strategy 66
Active Feeding Stages 67
Results and Discussion 67

CHAPTER 5 BIOLOGY OF THREE SAC SPIDERS ATTACKING CITRUS LEAFMINER 83
Introduction 83
Materials and Methods 84
Rearing on Different Artificial Diets and Natural Diets 84
Effect of Artificial Diets on the Survival of *Hibana velox* 87
Comparison between artifical and natural diets on survival of *C. inclusum*, *H. velox*, and *T. volutus* 87
Biology of the Sac Spiders 89
Results and Discussion 90
Rearing on Different Artificial Diets 90
Comparison Between Artificial Diet and Natural Diet 96
Biology of the Three Sac Spiders 100

CHAPTER 6 SELECTIVE TOXICITY OF SOME PESTICIDES TO *HIBANA VELOX*, A PREDATOR OF CITRUS LEAFMINER 111
Introduction 111
Materials and Methods 112
Surface Coating Method 113
Dipping Method 113
Results and Discussion 115

CHAPTER 7 DISSERTATION SYNOPSIS 121
Summary of Research Results 121
Conclusion and Recommendation 126

APPENDIX A. KEY TO THE PREDATORY SPIDERS IN LIME ORCHARDS IN HOMESTEAD FLORIDA 130

APPENDIX B SURVIVAL OF HUNTING SPIDER, *HIBANA VELOX* (ARANEAE ANYPHAENIDAE), RAISED ON DIFFERENT ARTIFICIAL DIETS(Accepted for publication in the Journal of Arachnology) 145

APPENDIX B PREPARATION OF BANANA MEDIUM FOR MASS REARING OF *DROSOPHILA MELANOGASTER* (Based on Yoon, 1985) . . . 154

REFERENCES CITED . . . 155

BIOGRAPHICAL SKETCH . . . 189

LIST OF TABLES

Table page

1-1 Literature on spider fauna in orchards ... 12

1-2 Literature on spider fauna in meadows and pastures ... 13

1-3 Literature on spider fauna on vegetables ... 13

1-4 Literature on spider fauna of cereals and forage ... 14

1-5 Literature on spider fauna on other crops ... 15

2-1 Description of the lime orchards included in the survey ... 22

2-2 Weekly count of spiders (representation by guild) collected in three lime orchards at Homestead, Florida. ... 29

2-3 Number of predators collected in three lime groves using three different sampling techniques (Homestead, FL. Summer 1996) ... 32

2-4 Abundance of commonly encountered spiders in lime orchards using visual, shake-cloth, and DVAC sampling methods ... 33

2-5 Abundance and diversity of spiders in nonsprayed and sprayed orchards. ... 36

3-1 Result of the feeding test for commonly encountered spider species in lime groves on CLM larvae. ... 50

3-2 Efficacy of the second and third nymphal spiderling stages of the three species of spiders on CLM larvae ... 52

3-3 Average number of prey consumed per *Hibana velox* provided with different densities of 1st and 2nd instar larvae of *P. citrella* ... 57

4-1 Activity pattern of the three species of hunting spiders in six 4-hour intervals ... 68

4-2 Duration of time for predation activity and the number of citrus leafminers consumed in 24 hours by the three species of hunting spiders ... 75

4-3 Percent CLM consumption of the different nymphal stages and adult stage of the three species of hunting spiders ... 76

5-1 Nutritional composition of milk plus yolk and soybean diets based on the manufacturer's nutritional analysis per 100 ml of media ... 85

5-2 Percent survival of *Hibana velox* after 10 weeks on three different artificial diets and the control raised under laboratory conditions at 27°C and 80%RH ... 95

5-3 Life histories of *C. inclusum*, *H. velox*, and *T. volutus* reared from egg to maturity under controlled laboratory conditions (27°C, 80% RH) ... 109

6-1 Pesticides tested for the laboratory bioassay and the pests that they are recommended to control (Knapp, 1996) ... 112

6-2 LD50 values of pesticides showing moderate to high toxicity on *H. velox* ... 118

LIST OF FIGURES

Figure ... page

1-1 Developmental stages of citrus leafminer ... 5

1-2 Heavy infestations of citrus leafminer ... 6

2-1 Abundance of predatory arthropods in lime orchards during summer, 1995 at Homestead, Florida ... 24

2-2 Abundance of the different species of web-building spiders in lime orchards at Homestead, Florida during June to August, 1995 ... 26

2-3 Abundance of the different species of wandering spiders (hunter and ambushers) in lime orchards at Homestead, Florida during June to August, 1995 ... 27

2-4 Weekly abundance of web-building spiders and hunting spiders collected from lime orchards at Homestead, Florida ... 28

2-5 Comparison of the abundance of web-building and hunting spiders collected by the different sampling methods ... 34

2-6 Difference in the abundance of spiders and other insect predators in nonsprayed and sprayed orchards ... 37

2-7 Difference in the abundance of the two spider guilds in nonsprayed and sprayed orchards ... 38

2-8 Dendogram of web-building spider abundance based on average linkage cluster (CL) analysis ... 40

2-9 Dendogram of hunting spider abundance based on average linkage cluster (CL) analysis ... 41

3-1 Experimental set-up for the laboratory feeding test ... 44

3-2 Experimental set-up for the feeding efficiency test of the three species of sac spiders on CLM under greenhouse conditions ... 46

3-3 Experimental set-up for the feeding efficiency test of *H. velox* on CLM using outdoor cages 48

3-4 *Chiracanthium inclusum* feeding on CLM larva 53

3-5 *Hibana velox* feeding on CLM larva 54

3-6 *Trachelas volutus* feeding on CLM larva. 55

3-7 Predation rate of *C. inclusum*, *H. velox*, and *T. volutus* on CLM larvae under greenhouse conditions 56

3-8 Effect of density of citrus leafminer larvae on the number consumed upon exposure to *Hibana velox* 58

3-9 Effect of the different number of spiders on percent CLM consumption 59

3-10 Esterase pattern of CLM, *C. inclusum*, and *T. volutus* 61

3-11 Esterase pattern of CLM and *H. velox* 62

4-1 Duration of locomotory activities (in hours) in three species of hunting spiders measured in six-hour intervals 69

4-2 *Chiracanthium inclusum* touching or sensing the CLM larva by its hindleg 71

4-3 Predation sequence of *Chiracanthium inclusum*. A) searching, B) feeding, and C) after feeding. 72

4-4 Predation sequence of *Hibana velox*. A) searching, B) feeding, and C) after feeding. 73

4-5 Predation sequence of *Trachelas volutus*. A) searching, B) feeding and C) after feeding 74

4-6 Developmental growth of male *Chiracanthium inclusum* raised using CLM larvae 78

4-7 Developmental growth of female *Chiracanthium inclusum* raised using CLM larvae 79

4-8 Developmental growth of *Hibana velox* raised using CLM 80

4-9 Developmental growth of male *Trachelas volutus* raised using CLM larvae 81

4-10 Developmental growth of female *Trachelas volutus* raised using CLM larvae. 82

5-1 Rearing set-up for the combination diet 88

5-2. Rearing set-up for the spiders using larvae of CLM. 88

5-3 Rearing set-up for the spiders using *Drosophila* adults 88

5-4 Percent survival of *H. velox* reared on different artificial diets 91

5-5 Percent spider survival and percent molting of *H. velox* reared on soybean milk diet 92

5-6 Percent spider survival and percent molting of *H. velox* reared on milk+yolk diet. 93

5-7 Percent spider survival and percent molting of *H. velox* reared on combination diet. 94

5-8 Developmental growth of *C. inclusum*, *H. velox*, and *T. volutus* reared on artificial combination diet 97

5-9 Developmental growth of *C. inclusum*, *H. velox*, and *T. volutus* reared on larvae of CLM 98

5-10 Developmental growth of *C. inclusum*, *H. velox*, and *T. volutus* reared on adults of *Drosophila* 99

5-11 Egg mass of *Chiracanthium inclusum* 101

5-12 Egg mass of *Hibana velox* 103

5-13 Egg mass of *Trachelas volutus* 104

5-14 Complete developmental cycle of *Chiracanthium inclusum* reared under laboratory conditions 105

5-15 Complete developmental cycle of *Hibana velox* reared under laboratory conditions 106

5-16 Complete developmental cycle of *Trachelas volutus* reared under laboratory conditions 107

6-1 Surface coating method 114

6-2 Dipping method 114

6-3 Percent mortality of spiders exposed to three different concentrations of Avermectin, Imidacloprid Provado, Imidacloprid Admire, and Copper-Tri Basic 116

6-4 Percent mortality of spiders exposed to three different concentrations of five broad-spectrum insecticides 117

6-5 Percent mortality of spiders exposed to three different concentrations of naturally derived pesticides 119

A-1 *Lyssomanes viridis* 137

A-2. *Phidippus regius* 137

A-3 *Hentzia palmarum* 138

A-4 *Hibana velox* 138

A-5 *Chiracanthium inclusum* 139

A-6 *Trachelas volutus* 139

A-7 *Theridion sp.* 140

A-8. *Nephila clavipes* 140

A-9 *Gasteracantha cancriformis* 141

A-10 *Acacesia hamata* 141

A-11 *Eriophora ravilla* 142

A-12 *Neoscona arabesca* 142

A-13 External morphology of spider showing the dorsal view with male and female Palpi (a), and ventral view with epigynal structure (b) [modified from Barrion & Litsinger 1995] 143

A-14 Leg components (a), mouthparts (b), eye morphology and pattern showing Eight type (c), and six type (d) [modified from Barrion & Litsinger 1995] 144

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

EVALUATION OF PREDATORY SPIDERS AS BIOLOGICAL CONTROL AGENTS OF CITRUS LEAFMINER, PHYLLOCNISTIS CITRELLA, IN LIME ORCHARDS AT HOMESTEAD, FLORIDA

By

Divina Medina Amalin

May 1999

Chairman: Jorge E. Peña
Major Department: Entomology and Nematology

Biological and ecological investigations were conducted to determine the importance of predaceous spiders in the overall management of the citrus leafminer (CLM), *Phyllocnistis citrella* Stainton, in lime orchards at Homestead, Florida. A survey of predaceous arthropods showed that spiders significantly outnumbered green lacewings (*Chrysoperla rufilabris*), coccinellids (*Harmonia* sp.), and ants (*Myrmelachista* sp.). Analysis of the spider species composition revealed a rich spider community in lime orchards. A total of nine families, 24 genera, and 16 identifiable species of spiders were recorded. The species were grouped into three guilds: web-builders, hunters, and ambushers. *Theridion* sp. was the most abundant of the web-builders and *Chiracanthium inclusum*, *Hibana velox*, and *Trachelas volutus* were the most frequent hunters. The population of ambushers (i.e. *Misumenops* sp.) was low in all orchards included in the survey.

Feeding tests conducted under laboratory conditions demonstrated that four species of spiders (i.e. sac spiders, *C. inclusum*, *H. velox*, *T. volutus* and the jumping spider *Hentzia palmarum*) use CLM as prey Gut content analysis confirmed the feeding choice of the three sac spiders Among the sac spiders, *H velox* was a more efficient predator of CLM larvae than *C. inclusum* and *T volutus* Studies performed under field conditions, demonstrated *H velox* consumption rate of CLM larvae increases proportionally as the densities of prey increase

Results from a study of predatory behaviors confirmed that the three species of sac spiders are nocturnal hunters, and detect their prey through vibration of the leaf substrate This vibration is the product of CLM larval and prepupal movement

The life cycles of *C. inclusum*, *H velox*, and *T volutus* were determined *Chiracanthium inclusum* and *T. volutus* fed on CLM from their first molt through adult stage whereas *H velox* consumed CLM from the 1st to the 7th molt and not during the adult stage. Survival of *C. inclusum* *H velox*, and *T volutus* was compared between natural diets and artificial diets

During a survey of sprayed and nonsprayed lime orchards, spiders were more abundant in the nonsprayed orchards than in those with heavy application of pesticides Laboratory bioassay tests confirmed that broad spectrum pesticides have a significant lethal effect on spiders, while biopesticides such as *Bacillus thuringiensis*, botanical pesticides (i e. neem extract) and petroleum oil were less toxic to spiders. The abundance and predation potential of these spiders indicate that they should be protected from the harmful effects of pesticides. A taxonomic key for the predaceous spiders discovered during this study was developed

CHAPTER 1
INTRODUCTION

Limes are acid citrus fruits, and consist of two distinct species, *Citrus aurantifolia* (Christm.) Swingle and *Citrus latifolia* Tanaka. They are commonly known as Persian lime and Key lime, respectively. Key lime originated from Asia whereas Persian lime is of unknown origin (Malo & Campbell 1991). Limes traveled with the world's explorers to the different continents of the world (Roy et al. 1996). They were introduced to the New World by the Spanish and Portuguese explorers during the early 16th century (Roy et al. 1996). Between the two species of limes, Persian lime became the favorite and now is widely distributed in the lowland tropics and warm subtropical areas of the world.

Persian lime first arrived in the USA in California between 1850 and 1880 from Tahiti, where it acquired its other name Tahiti lime. It is also commonly called Bearss lime in California (Hume 1957). Orchards of Tahiti limes were first planted in central Florida around 1887. However, due to the occasional freezes in central Florida, plantings of Tahiti lime moved to the southern tip of the state. Today, the major lime-producing region in the continental USA is in Dade County, Florida. Among the 15 tropical fruits that are commercially grown in Dade County, Tahiti lime is in the top three with mangoes and avocados (Campbell 1979, Roy et al. 1996). The production area before the devastating Hurricane Andrew in 1992 was 6,700 acres (2,713 ha) which comprised more than 90% of Tahiti lime production in the USA. However, Hurricane Andrew reduced the Tahiti lime acreage in south Florida to only 2,235 acres (905 hectares). Nevertheless, the lime acreage is now increasing and the most optimistic estimate predicts that south Florida's Tahiti lime acreage will increase gradually to 4 000 acres (1,619 hectares) (Roy et al. 1996). In addition to the USA, the following countries have commercial Tahiti lime orchards. Australia, Belize, Brazil, the Bahamas, Cuba, Dominican Republic, El Salvador, Guatemala, Honduras, Israel, Mexico, Nicaragua, Surinam, and Venezuela. The major Tahiti lime producers and exporters, in order of importance, are Mexico, Brazil, Israel, and Australia.

Tahiti lime is the most consumed lime species, particularly in the USA, Japan and Europe (Roy et al. 1996). Limes are important as fresh and processed fruits. Fresh fruits, frozen and canned juices are used as beverages, for marinating fish and meats, and as food seasoning. Several essential products can be obtained from lime, i.e. citric acid, citrate of lime, concentrated lime juice, and lime oil.

Although the unique climate of south Florida is ideal for the production of Tahiti limes, diseases and arthropod pests also thrive in the warm, humid climate, providing a challenge to the lime industry. The complex of arthropod pests affecting citrus in Florida is diverse (Browning et al. 1995). Among the chronic pests are several mite species: citrus rust mite, *Phyllocoptruta oleivora* (Ashmead), pink citrus rust mite, *Aculops pelekassi* (Keifer), citrus red mite, *Panonychus citri* (McGregor), Texas citrus mite, *Eotetranychus banksi* (McGregor), flat mites, *Brevipalpus* spp., and broad mite, *Polyphagotarsonemus latus* (Banks). Several species of homopteran pests occur in Florida citrus orchards. The most important is the brown citrus aphids, *Toxoptera citricida* (Kirkaldy). Five species of root weevils are recorded in citrus orchards in Florida: sugarcane rootstalk borer weevil, *Diaprepes abbreviatus* (L.), little leaf notcher, *Artipus floridanus* (Horn), citrus root weevil, *Pachnaeus litus* (Germar), northern citrus root weevil, *Pachnaeus opalus* (Olivier), and Fuller's rose beetle, *Asynonychus godmani* (Crotch). *Diaprepes abbreviatus* is the most important among these five species of root weevil. Recent invaders of Florida citrus are brown citrus aphids, *Toxoptera citricida* (Kirkaldy), and citrus leafminer, *Phyllocnistis citrella* Stainton. Both of these species are native to Asia. The brown citrus aphid is highly efficient in transmitting tristeza virus, causing decline in susceptible citrus cultivars. Citrus leafminer feeding results in citrus plants with distorted and reduced young shoots

Severe pressures from citrus leafminer cause decrease in yields and quality (Knapp et al 1995, Heppner 1995, Burgeous & Constantin 1995).

Baseline Information about the Test Organisms

Citrus Leafminer

The citrus leafminer (CLM), *Phyllocnistis citrella* Stainton is one of the major pests of *Citrus* species. Other related species of *Citrus* as well as native Rutacese are potentially at risk. The species was first described in Calcutta, India (Stainton 1856) and it is considered native to south and Southeast Asia (Schauff & LaSalle 1996) This Asian species is currently widely distributed and found in many countries in the world where citrus is grown (Heppner 1993, Knapp et al. 1995) Heppner (1993) provided distributional information for CLM, which included 6 countries in Africa, 24 countries in Asia, and 6 countries in the Pacific Region The distributional information was updated by Knapp et al. (1995) The first report of its occurrence in the New World was in mid 1993 at Homestead, Florida (Heppner 1993, Knapp et al 1995) In less than a year, it spread into all major citrus growing areas of the state, southern USA, the Caribbean Region, and the Americas (Heppner 1993, Knapp et al 1995, Schauff, & La Salle 1996) In 1993, citrus leafminer infestation in south Florida was reported on about 200 acres of Persian limes (Heppner 1993)

Biology of the citrus leafminer

The basic biology of the citrus leafminer, *Phyllocnistis citrella* Stainton, had been studied by several workers in different countries, i.e. Sudan (Ba-Angood 1977), Yemen (Ba Angood 1978), Egypt (Badawy 1969) Philippines (Barroga 1968), India (Bhumannavar & Singh 1983, Fletcher 1914 & 1920, Pandey and Pandey 1964, Sohi & Verma 1966, Sontakay & Gupta 1945), China (Huang & Huang 1989, Liu & Zeng 1981), Taiwan (Lo & Chiu 1988) and Japan (Anon. 1959, Clausen 1931, Hamamura 1980, Ikemoto 1972, Kuriseka 1928, Yamamoto 1968, 1969, & 1971)

The biology of CLM is typical of other species of leafmining moths (Auerbach & Simberloff 1989, Clausen 1927) Knapp et al (1993) summarized the biology of CLM based on published literature as follows Small eggs (Figure 1-1) are laid singly, usually on the underside of the young leaves of the host plants They are transparent when newly laid and turn opaque when they are ready to hatch. Eclosion occurs within 2-10 days. The hatching larva (Figure 1-1) produces serpentine mines beneath the leaf epidermis where they are protected during their feeding cycle. Larvae undergo four instars (including the specialized prepupal stage) Larval development lasts from 5 to 20 days. The pupa (Figure 1-1) is contained in a cell produced on the leaf edge by the prepupa. Pupal development requires 6-22 days, after which, the adult (Figure 1-1) emerges to continue the cycle. The total developmental cycle is about 13-52 days, depending on temperature conditions. Adults live for only a few days to one week, on average. Adults emerge about dawn and are active early in the morning Females lay eggs in the evenings They deposit 36-76 eggs over their life span, with an average of 48 eggs per female

Adult CLM usually prefers to oviposit on the expanding leaves of growing shoots Immediately upon hatching, CLM larvae bore through the leaf epidermis and begin drinking cell sap by lancing leaf cells with their sharp mandibles, thereby destroying the epidermis of the leaves. A silver mining trail known as a serpentine mine is the most obvious symptom of CLM infestation. Serpentine mines are usually on the abaxial surface of the leaves but can also be found on the adaxial surface (Pandey & Pandey 1964) The pupation chamber is usually near the leaf margin, the edge of which is rolled over During severe infestations (Figure 1-2), the leaves become curled and distorted, which may harbor mealybugs (Heppner 1993) The damaged area turns into a chlorotic patch, which may become necrotic Damage from CLM hinders the photosynthetic activity of the plant by reducing the leaf surface area responsible for capturing energy for plant growth Schaffer

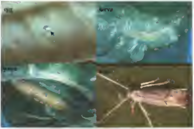

Figure 1.1 Developmental stages of citrus leafminer

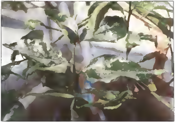

Figure 1.2 Heavy infestation of citrus leafminer

et al (1997) reported that the percentage of leaf area damaged by CLM and the subsequent reductions in net photosynthesis are related to the duration of mining and the number of larvae per leaf Succulent branches of green shoots and fruits may be attacked by leafminers during high population pressure Young trees suffer the most and heavy infestations on nursery trees and newly planted trees in an orchard cause reduced growth (Knapp et al 1995).

Control measures

Pesticides provide a rapid means of suppressing CLM populations especially during heavy infestations Control of CLM in the USA is accomplished through biological control, however, in other countries CLM control is accomplished by spray regimes of various pesticides (Ahmad 1988, Atwal & Verma 1970, Awate et al 1976, Ayoub 1960 Badawy 1968, Batra & Sandhu 1980, 1981a, 1981 b, Bindra 1957, Bohlen 1973, Butani 1979, Ela 1955, Hanifa & Palaniswamy 1977, Heppner 1993, Ito et al. 1962 Kohno & Makino 1969, Mo et al. 1981, Nagalingam & Savithri 1983, Oes-Dharma 1969, Peña & Duncan 1993, Radke & Kandalkar 1988 Radke & Thakare 1989 Raju et al 1977, Reddy et al 1989, Shewale et al 1983, 1987, Valand et al 1992, Vekateswarlu & Ramapandu 1992, Verma & Sohi 1967, Vivekanandan & Naganathan 1983, Wu & Tao 1977, Yamamoto 1972)

CLM resistance to several pesticides has been reported due to repeated applications within a season (Tan & Huang 1996) In China, for instance, many of the original pesticides (mostly pyrethroids and organophosphates) are no longer used (Tan & Huang 1996 Huang & Li 1989, Liu 1990) A similar scenario occurred in Japan (Gyoutoku et al 1996) In Florida, evaluation of several pesticides against CLM revealed that effective chemical control is difficult to attain (Knapp et al. 1995) Thus, of approximately 20 pesticides tested, only five were recommended for CLM control in Florida (Knapp 1996) There is an urgent need to develop alternative non-chemical control measures to avoid insecticide resistance and to conserve the natural enemy complex (Parker 1980, Peña & Duncan 1993). There are some contradictory reports regarding the effect of pesticides on CLM. For instance, in citrus, Ren and Wu (1989) reported that pyrethrins and dimephenol were less harmful to chalcid and eulophid wasps and other natural enemies of CLM. On the contrary, Huang and Li (1989) showed that pyrethrin kills the natural enemies and inevitably leads to secondary pest outbreaks. The harmful effects of pesticides on natural enemies have been verified through the survey of natural enemies in sprayed and nonsprayed orchards. Native parasitoids of CLM have been found also in Florida citrus orchards where no or few chemical sprays were used (Browning & Peña 1993, Browning et al. 1996, Chiu et al. 1985, Heppner 1993, Peña & Duncan 1993). In addition, most citrus pests are under effective biological control in Florida (Browning 1994). It is desirable to have products that can help to maintain CLM population at low densities without causing an imbalance in the biological control-oriented IPM program in Florida citrus production system. Pesticides known to be selective for some biological control agents have been recommended in some areas. In Australia, petroleum spray oil is recommended as a larvicide for CLM control. It was found to have low to moderate toxicity on predatory mites (Smith et al. 1997). In Florida, some pesticides i.e. Agrimek, Align, Eclipse, Micromite, Neemix, and petroleum oil are recommended for CLM control (Knapp 1996); however, very few studies have been documented on selectivity of pesticides on the natural enemies of CLM. One example was the study conducted by Villanueva-Jimenez (1998) on the effect of some pesticides used by the citrus growers in Florida on *Ageniaspis citricola* (Logvinovskaya), an introduced parasitoid of CLM. In Chapter 6 of this dissertation, the effect on the predatory spiders of some of the pesticides used in lime orchards will be presented.

Because of so many drawbacks with chemical control, other control measures for CLM have been sought by the researchers in different countries. Investigations have been conducted on cultural management, resistant citrus species, sex-pheromones, and biological control. Cultural control has been practiced to manage the population of CLM in China (Zhang et al. 1996), and includes bud removal and pruning of early shoots during warm weather to escape a heavy infestation of CLM. Trees are allowed to flush only during late autumn when the CLM population is lowest. These cultural practices are not feasible in Florida due to high labor cost and impracticality.

Resistance of *Citrus* species to CLM is not yet well studied. In India, 34 species of citrus were tested for resistance against the CLM (Sandhu & Batra 1978a, Singh & Rao 1980, Singh et al. 1989, Verma 1989). The most resistant species was mandarin, *Citrus reshni*, and the most susceptible was the lime species, *C. latifolia*. Other experiments in Sudan and in Australia (Badawy 1968, Wilson 1991, Zhang et al. 1996) confirm the same general pattern of resistance, with mandarin, *C. reshni*, as the most resistant variety followed by orange, *C. sinensis*, and lime, *C. latifolia*. In Spain, 9 citrus-related species and 349 citrus rootstocks were screened for resistance to CLM (Jacas et al. 1997). Laboratory screening results showed different levels of resistance among the citrus rootstocks evaluated. However, the resistance levels were not high enough to recommend a breeding program for *P. citrella*. Nevertheless, Jacas et al. (1997) found two citroids, *Murraya koenigii*, and *Glycosmis pentaphylla*, exhibiting antibiosis to the first instar CLM larvae. This suggests a source of resistance genes for further breeding.

Behavioral control using sex-pheromones has been investigated for CLM. The sex pheromone compounds used as sex attractants for CLM were identified as (Z-Z)-7, 11-Hexadecadienyl acetate and (Z,E)- 7, 11-Hexadecadien-1-ol (Ando et al. 1985). These compounds were discovered originally from *Pectinophora gossypiella* (Lepidoptera Gelechiidae) (Hummel et al. 1974). Consequently, the use of the non-specific sex-pheromone for trapping CLM had inconsistent results. In Japan, pheromone traps have been used successfully to trap CLM (Ando et al. 1985, Ujiye1990) and without success in other countries (Caleca & Lo Verde 1996, Malausa et al. 1996), i.e. China (Tongyuan et al. 1989), Italy (Ortu 1996), and in Spain, Florida, and Turkey (Jacas &

Peña 1999, in press). Jacas and Peña (1999, in press) hypothesized that the inconsistency in the effectiveness of the CLM sex-pheromone was caused by the lack of specificity of the sex-pheromone found in Japan. Geographical variation in pheromone composition has been reported for other Lepidoptera (Klun 1975, Lofstedt et al. 1986, Peña et al. 1988), which could also be the case for CLM.

Biological control appears to be the most promising control measure against CLM. Various species of natural enemies (pathogens, parasitoids, and predators) have been evaluated against CLM (Heppner 1993, Zhang et al. 1996, Argov & Rossler 1996). The efficacy test of the entomogenous nematode, *Steinernema carpocapsae* (Weiser) for controlling CLM has been carried out in Thailand and Australia. Laboratory tests revealed that CLM mortality ranged from 22.72-80%. Nevertheless, Morakote and Nanta (1996) reported that the use of *S. carpocapsae* against CLM is not commercially acceptable at the concentrations tested. Worldwide, various species of parasitoids of CLM have been identified. For instance, in Southeast Asia alone, 58 species have been recognized as CLM parasitoids (Heppner 1993, Ujiye et al. 1996). In Florida, at least six species of native parasitoids have been found since the arrival of CLM (Browning & Peña 1994, Browning et al. 1996). Moreover, two species of parasitic wasps, *Ageniaspis citricola* and *Cirrospilus quadristiatus* have been introduced into Florida from Australia to control CLM. These parasitoids are an important addition to the already existing complex of parasitoids and predators attacking CLM in Florida (Hoy & Nguyen 1994).

Predaceous arthropods are believed to make an important contribution to the mortality of CLM. In China, two species of lacewings, *Ankylopteryx octopunctata* (Frazer) and *Chrysopa boninensis* (Okamoto), and an unidentified ant have been found attacking CLM (Zhao 1989, Zhang et al. 1996). Lacewings are very important biological control agents not only for CLM but also for other pests of grain, cotton, vegetables, fruit and other crops (Zhang et al. 1994). In Thailand, the predators of CLM are also two species of green lacewings, *Ankylopteryx octopunctata* (Frazer) and *Chrysopa basalis*

(Navas) and an unidentified ant. Likewise in Israel, various predators i.e. spiders were observed in the field to prey upon CLM (Argov & Rossler 1996). In south Florida, several predators such as lacewings, *Chrysoperla rufilabris* (Burmeister), flower bug, *Orius insidiosus* (Say), an unidentified ant, and various species of spiders were considered important in reducing peak population of CLM (Browning & Peña 1995, Amalin et al. 1995, Peña & Subramanian, unpublished data). However, to date, no systematic study has been made to identify these natural enemies of CLM in Florida or assess their effects on the pest's population. In this dissertation, Appendix A provides the identification key to the predatory spiders in lime orchards and chapters 3 and 4 address the question on assessment of predatory spiders for biological control of CLM as well as the predatory strategy of the spiders on CLM.

Spiders

Spiders belong to the Order Araneae and Class Arachnida. They are one of the ubiquitous groups of predaceous organisms in the animal kingdom. Current records show that ≥ 30,000 species (Riechert & Lockley 1984) are widely distributed, occupying all terrestrial habitats (Turnbull 1973). Surveys conducted by several researchers have shown that spiders are a large and frequent part of the generalist predatory arthropod fauna (Kagan 1943, Whitcomb et al. 1963a, 1963b, Aguilar 1968, Leigh & Hunter 1969, Howell & Pienkowski 1971, Wheeler 1973, Yeargan & Dondale 1974, Dondale et al. 1979, Barrion 1982, Dean et al. 1982, Mansour et al. 1982, Culin & Yeargan 1983, Barrion & Litsinger 1994, Plagens 1985, Amalin & Barrion 1992).

Spiders have an important influence in the dynamics of the arthropod pest's population in natural and agricultural landscapes. For instance, in the natural landscape, Van Hook (1971) found that the wolf spider, *Lycosa sp.* (Lycosidae) consumed 21% of the total arthropods in a grassland ecosystem. In another study, Moulder and Reichle (1972) concluded that spiders are the most important predators in a *Liriodendron tulifera* community Some studies on the ability of spiders to limit growth of associated insect populations have been documented An experiment on a forest floor system by Clarke and Grant (1968) indicates that spiders managed the populations of *Collembola* and other insects Several studies on the spider fauna in agricultural landscapes have been published Tables 1-1 to 1-5 list the different studies on the spider fauna in different agroecosystems.

Table 1-1 Literature on spider fauna in orchards

Agroecosystem	Authors	Agroecosystem	Authors
orchards	Chant (1956)	citrus	Argov & Rossler (1996)
	Dondale (1956, 1958)		Barron & Taylo (1989)
	Dondale et al (1979)		Carroll (1980)
	Dondale (1966)		Kazhotau (1979)
	Hukusima (1961)		Mansour et al (1982)
	Hukusima & Kondo (1962)		Muma (1973 1975)
	Kraemer (1961)		Nohara & Yasumatsu (1965)
	Legner & Oatman (1964)		Sadana & Kaur (1974)
	MacLellan (1973)		Shulov (1938)
	Mansour et al (1980a, b, c)		
	Mansour et al (1981)	banana	Harrison (1968)
	McCaffrey & Horsburgh (1978 1980)		
	Okuma (1973)	grapes	Kara (1978)
	Puhringer (1982)		Sadana & Sandhu (1977)
	Putman (1967)		
	Putman & Herne (1966)	strawberry	Taksdal (1973)
	Specht & Dondale (1960)		Almquist (1981)
			Dippenaar-Schoeman (1976 1979a, b)
coconut	Tothill et al. (1930)		
	Howard & Edwards (1984)		

Table 1-2 Literature on spider fauna in meadows and pastures.

Agroecosystem	Authors	Agroecosystem	Authors
meadows	Benz & Nyffeler (1980) Beyer (1981) Nyffeler (1986) Breymeyer (1967) Dondale (1971, 1979) Dondale & Binns (1979) Dondale et al. (1970 1972) Duffey (1974) Fox & Dondale (1972)	meadows	Kajak (1960 1962, 1971 1978, 1980) Kajak & Jakubczyk (1979) Kajak et al. (1968 1971) Maurer (1974 1975) Nyffeler & Benz (1979b, 1981) Schaefer & Haas (1979) Thaler et al. (1977 1979) Vilbaste (1965) Wolcott (1937)
pasture	Breymeyer (1979) Cherrett (1964) Delchev & Kajak (1974) Duffey (1962) Howard & Oliver (1978)	pasture	Peck & Whitcomb (1978) Polenec (1968) Whitcomb et al. (1963 a) Wolcott (1937)

Table 1-3 Literature on spider fauna on vegetables.

Agroecosystem	Authors	Agroecosystem	Authors
sugar beet	Beyer (1981) Czajka & Goos (1976) Goos (1973) Nyffeler (1986)	potato	Amalin & Barrion (1992) Czajka & Kania (1976) Dunn (1949) Galecka (1966) Nyffeler (1986) Luczak (1974 1975, 1976, 1979)
cabbage	Kayashima (1960) Suzuki & Okuma (1975)		
		Sweet potato	Amalin & Vasquez (1993) Amalin et al. (1991)
leys	Huhta & Raatikainen (1974)		
		soybeans	Blickenstaff & Huggans (1962) Culin & Rust (1980) Deitz et al. (1976) Lesar & Unzicker (1978a, b) Turnipseed (1975) Whitcomb (1980)
rape	Beyer (1981) Nyffeler & Benz (1979a)		
kohlrabi	Beyer (1981)		
marrowstem kale	Beyer (1981)	cole	Pimentel (1961)
asparagus	Dingler (1935)	guar	Rogers & Horner (1979)

Table 1-4. Literature on spider fauna of cereals and forage

Agroecosystem	Authors	Agroecosystem	Authors
cereals	Ashikbayev (1973)	cereals	Luczak (1974, 1975 1976, 1979)
	Basedow (1977)		Muniappan & Chada (1970a)
	Beyer (1981)		Nyffeler & Benz (1979a)
	Brasse (1975)		Nyffeler & Benz (1980 b)
	Cottenie & De Clercq (1977)		Nyffeler & Benz (1981)
	De Clercq (1979)		Raatikainen & Huhta (1968)
	Dietrich & Goetz (1974)		Vickerman & Sunderland (1975)
	Fraser (1982)		
rice	Anonymous (1979)	rice	Kiritani & Kakiya (1975)
	Barrion & Litsinger (1995)		Kiritani & Kawahara (1977)
	Chu & Okuma (1970)		Kiritani et al (1972)
	Chu et al (1974)		Kobayashi (1975 1977)
	Choi et al (1978)		Kobayashi & Shibata (1973)
	Chu & Wang (1972, 1973)		Koyama (1972 1975 1976
	Chu et al (1975, 1976a,b,c)		Lucero & Raros (1975)
	Chu et al (1977)		Miyai et al (1978)
	Gavarra & Raros (1975)		Okuma (1968)
	Hamamura (1969, 1971)		Okuma (1974 1977)
	Hashimoto (1974)		Okuma & Wongsiri (1977)
	Heong et al (1991)		Okuma et al (1978)
	Hinno & Kiritani (1978)		Paik & Kim (1973)
	Hokyo et al (1978)		Paik et al (1974)
	Ito et al (1962)		Salinas & Raros (1975)
	IRRI Ann. Report (1973, 1974)		Samal & Misra (1975)
	IRRI Ann. Report (1976 1977)		Sasaba & Kiritani (1974)
	IRRI Ann Report (1978)		Sasaba et al (1970)
	Kalode (1976)		Sasaba et al (1973a, b)
	Kakiya & Kiritani (1978)		Suzuki & Kiritani (1974)
	Kang & Kiritani (1979)		Tanaka (1973 1975)
	Kawahara (1975)		Tanaka & Hamamura (1968)
	Kawahara & Kiritani (1975)		Toyoda & Yoshimura (1966)
	Kawahara et al (1969 1971)		Woods & Harrel (1976)
	Kiritani (1977, 1979)		Yaginuma (1965)
			Yamano (1977)

Table 1-4 continued

Agroecosystem	Authors	Agroecosystem	Authors
alfalfa	Balogh & Loksa (1956) Nyffeler (1986) Chauvin (1960, 1967) Culin & Yeargan (1983) Nyffeler (1986) Howell & Pienkowski (1971) Luczak (1975)	alfalfa	Muniappan & Chada (1970b) Schlinger & Dietrick (1960) Wheeler (1973) Yeargan (1975a, b) Yeargan & Cothran (1974a, b) Yeargan & Dondale (1974)
clover	Beyer (1981) Bonet (1958) Nyffeler (1986)	corn	Everley (1938) Sharma & Sarup (1979) Singh & Sandhu (1976)
sorghum	Bailey & Chada (1968)	wheat	Doane & Dondale (1979)

Table 1-5 Literature on spider fauna on other crops.

Agroecosystem	Authors	Agroecosystem	Authors
cotton	Aguilar (1974) Battu & Singh (1978) Bishop (1979, 1980, 1981) Bishop & Blood (1980) Burleigh et al. (1973) Byerly et al. (1978) Clark & Glick (1961) Dorris (1970) Johnson et al. (1976) Kagan (1943) Leigh & Hunter (1969)	cotton	Lockley et al (1979) McDaniel & Sterling (1979) Pfrimmer (1964) Pieters & Sterling (1974) Room (1979) Shepard & Sterling (1972) Stam et al. (1978) Wesmann (1955) Whitcomb & Bell (1964) Whitcomb & Tadic (1963) Whitcomb et al. (1963a, b)
sugarcane	Barbosa et al. (1979) Hensley et al. (1961) Negm & Hensley (1969)	tea	Kaihotsu (1979) Terada (1977) Terada et al. (1978)
mulberry	Kayashima (1967, 1972) Park et al. (1973)	coffee	Robinson & Robinson (1974)
sunflower	Seiler et al. (1987)	taro	Nakasuji (1978)

The importance of spiders as biological control agents was already known thousands of years ago. In China, the use of spiders for pest control dates back 2000 years (Sparks et al. 1982). Since then, spiders have been recorded as important predators in many agricultural crops. A classical example of a successful biological control system using spiders was reported on rice. The wolf spider *Lycosa pseudoannulata* Boes. Et. Str., successfully controlled the brown planthopper, *Nilaparvata lugens* Stal, which is the major pest of rice in Southeast Asia (Ooi & Shepard 1994, Kenmore et al. 1984, IRRI 1975, 1985). In Britain, Chant (1956) reported that theridiids and erigonids suppressed orchard mites. In Australia, another species of a small theridiid, *Achaearanea veruculata*, successfully controlled a tortricid moth (MacLellan 1973). A study in an unsprayed peach orchard in the Niagara Peninsula showed that *Theridion murarium* Emerton and *Philodromus praelustris* Keyserling regulated the density of phytophagous mites (Putman 1967). Similar findings have been reported for other agricultural systems involving various insect pests (Yamanaka et al. 1973, Mansour et al. 1980a &1980b). The diversity of the spider population in almost all agroecosystems suggests the importance of spiders as predators of insect and other arthropods. In spite of the large number of existing studies, the significance of spiders as insect predators in most agroecosystems is still largely unknown.

Research Goals

The main goal of this dissertation research is to demonstrate the importance of predaceous spiders in the overall management of CLM population. This dissertation research has five major objectives: 1) to determine the predatory arthropod biodiversity in lime orchards, 2) to identify the species of spiders preying on CLM, 3) to test the efficacy of the most dominant species of spiders against CLM under laboratory, greenhouse, and field conditions, 4) to investigate predatory behavior of hunting spiders on CLM, and 5) to determine the effect of pesticides on the spider community.

Each of the research objectives provides answers to relevant questions on the ecology and biology of important spiders occurring in lime orchards in Homestead, Florida. In the course of the investigation the following questions have been asked:

Which spider species occurred in lime orchards? (species composition)
How many spiders per unit area occurred in lime orchards? (abundance of spiders)
What spider species feed on citrus leafminer? (feeding studies)
How much is the effect of spiders on CLM mortality? (predation assessment)
At which time of the day do the spiders feed? (feeding activity rhythm)
Which strategies do the spiders use to catch their prey? (hunting strategy)
How many prey per time unit do the spiders catch? (prey capture rate)
What is the biology of the important spiders? (biological studies)
What is the effect of chemicals on spider communities? (chemical effect)

Each of these questions has been addressed in separate chapters in this dissertation. The spider species composition and abundance of spiders in lime orchards are presented in Chapter 2. The results of feeding studies and predation assessment in the laboratory, greenhouse, and field conditions are contained in Chapter 3. The spider feeding activity rhythm and observations on the spider hunting strategy are provided in Chapter 4. The biology of the sac spiders is presented in Chapter 5. Lastly, the effect of pesticides on spider communities in lime orchards is provided in Chapter 6.

Ecological and biological knowledge on predatory spiders in lime orchards will lead us to better understand the role of spiders as natural enemies of CLM. It will greatly aid in the development of biological and integrated management of CLM.

CHAPTER 2
SURVEY OF SPIDERS OCCURRING IN LIME ORCHARDS IN HOMESTEAD, SOUTH MIAMI DADE COUNTY, FLORIDA

Introduction

There is a growing interest in the potential of spiders and other generalist predatory arthropods for control of pest species in different agroecosystems (Chiverton 1986, Quaintance & Brues 1905, Riechert & Bishop 1990). In deciduous orchards, spiders often constitute a large part of the predatory arthropod fauna (Dondale et al. 1979). Different investigations conducted in apple orchards demonstrated that spiders are important natural enemies of aphids, mites, and lepidopterans (Chant 1956, Dondale 1958, 1966, Dondale et al 1979, Mansour et al. 1980c, Wyss et al 1995). In peach orchards, spiders were also found to be an important factor in regulating the density of phytophagous mites (Putman 1967). Likewise, spiders have been observed by investigators in some countries as important predators of insect pests of citrus (Shulov 1938, Muma 1975, Cherry & Dowel 1979, Fitzpatrick et al. 1979, Carroll 1980, Badawi 1981). The hunting spider, *Chiracanthium mildei* (Clubionidae), was reported to be the most effective natural enemy of the scale *Ceroplastes floridensis* (Mansour & Whitcomb 1986). Cherry & Dowel (1979) indicated that spiders and the coccinellid *Delphastus pusillus* Lec. were the most abundant predators and reduced the population of citrus blackfly in Florida citrus agroecosystem. In Saudi Arabia, Badawi (1981) observed that two unidentified species of spiders were abundant on citrus orchards and actively preyed upon eggs and young larvae of the citrus butterfly, *Papilio demoleus* Linnaeus. Carroll (1980) stated that sac spider, *Trachelas pacificus* Chamberlin and Ivie (Clubionidae), is probably the most promising natural enemy of citrus pest arthropods in California. It is therefore of paramount importance to know the occurrence and abundance of these generalist predators in the ecosystem in order to protect and conserve them and eventually maximize their potential as biological control agents.

One way to contribute to the conservation of the naturally occurring biological control agents is by protecting them from the harmful effects of broad-spectrum pesticides. The effects of pesticides on spider populations have been shown in some studies (Riechert & Lockley 1984, Mansour 1987a, b, Wisniewska et al. 1993). For instance, there was a reduction on spider numbers in apple orchards sprayed with wide spectrum insecticides in Canada (Dondale et al. 1979, Dondale 1958), in England (Chant 1956) and New Jersey, USA (Specht & Dondale 1960). In Canada, it was reported that the population of the phytophagous mite predators, *Theridion* sp. Emerton and *Philodromus praelustris* Keyserling was higher in unsprayed peach orchards (Putman 1967). A decline of spider population in sprayed cotton fields was also reported in Israel (Mansour 1987b). Understanding changes in the community that has resulted from the use of pesticides is important to obtain the maximum control effect from spiders and other predators on pest populations. In lime, no studies have been conducted to look at the effect of this factor on the population of predatory spiders.

In this chapter, the diversity, abundance and species composition of predatory spiders in different lime growing areas in Homestead, Florida, has been presented. Efficiency of different sampling techniques for sampling predatory arthropods has been evaluated. The abundance of spiders and species composition in sprayed and unsprayed lime orchards has also been investigated. This investigation has assessed the relative impact of pesticides on spider population.

Materials and Methods

Preliminary Survey of Predatory Arthropods

All sampling was conducted from June 15, 1995, through August 15, 1995, in three commercial 2.0 – 4.0 ha lime orchards in Homestead, Florida. In all the orchards, the trees were planted 6.0 m between rows and 4.5 m between trees.

For each orchard, 15 randomly selected trees were surveyed every week for 8 weeks. Sampling of spiders was done by visually searching plant parts i.e. leaves, main stem, and branches, from 0.30m to 1.7m above ground. The searching time for each tree range from 5 to 10 minutes depending on the circumference of the tree. Samplings were done in the morning. All the spiders were collected in 20-ml laboratory glass vials containing 70% ethyl alcohol. The collections were transported to the laboratory for sorting, counting, and identification. Spider identification was done using published keys by Kaston (1978) and Roth (1993). Verification of spider identification was provided by G.B. Edwards, spider taxonomist at Division of Plant Industry, Gainesville, Florida.

Differences in spider densities by species in each spider guild (web-builders, and wanderers [i.e. hunters, and ambushers]) among the three orchards were subjected to a one-way analysis of variance (ANOVA). The means were compared by Duncan's Multiple Range Test (DMRT) (SAS 1989). The spider guild identification was based on predation behavior. The mean weekly count of wandering spiders was also compared to that of the web-building spiders using the Least Significant Difference (LSD). Other insect predators, i.e. green lacewings, coccinellids, and ants were also collected and counted. The weekly count mean for these groups was compared to that of the spiders using DMRT.

Comparison of Three Different Sampling Techniques

This study was done in three 2.5-ha lime orchards in Homestead, Florida. Sampling was conducted from May 25, 1996 to August 20, 1996 Three sampling methods were used to determine the density of predacious arthropods. Ten different trees were sampled for each method and orchard The first method included the arthropod numbers visually observed on leaf flushes of 10 randomly selected branches (30 76 cm in length) at the exterior canopy Sampling was done between 9 00 to 11 00 AM. Leaves webbed together were carefully inspected or unfolded to determine the presence of spiders in the retreat nest The second sampling method consisted of using a 1m x 1m shake-cloth placed under five branches clamped together and beaten 10 times with a wooden yardstick. Groups of five clamps were randomly selected from the tree canopy The third sampling method consisted of using a suction DVAC sampler (Modified CDC Backpack Aspirator-Model 1412) The collecting device was held at about 1 meter above ground and pointed toward the middle and bottom exterior portion of the canopy The operator moved clockwise around the tree

For all tested sampling methods, the predators were collected in 20-ml glass vials with 70% ethyl alcohol and brought back to the laboratory for sorting, counting and identification Spiders were grouped into two guilds based on predation behavior web-building and hunting groups

Means and variances were calculated for each sampling method for the two spider guilds Means were compared using DMRT Mean densities of the most common spiders were also calculated and compared using DMRT

Spiders in Sprayed and Nonsprayed Orchards

Spiders were sampled in six 2.5 to 4.5 ha lime orchards in Homestead, Florida. In all the orchards, the trees were 4.5 m tall and had canopies of approximately 5.0 m in diameter. The orchards included in the survey are described in Table 2-1.

In each orchard, 15 trees were selected randomly for each week from the middle of May, 1996 to August, 1996. Trees were individually inspected every week using visual sampling method following the procedure described in the preliminary survey. After the visual examination, the same tree was further sampled using the shake-cloth method as described in the comparison of sampling methods methodology. The number of spiders as well as the number of green lacewings, coccinelids, and ants were recorded.

Table 2-1. Description of the lime orchards included in the survey.

Orchard	Status	Location	Size (ha)	Pesticide Management
1	Commercial	Homestead, FL	4	Sprayed
2	Commercial	Homestead, FL	3.5	Sprayed
3	Experimental	TREC-Homestead, FL	4.5	Sprayed
4	Commercial	Homestead, FL	3.5	Not sprayed
5	Commercial	Homestead, FL	2.5	Not sprayed
6	Experimental	TREC-Homestead, FL	2.5	Not sprayed

Sprayed commercial orchards #1 and #2, Agrimek 0.15 EC + Petroleum oil 97% (10 fl oz/acre) for citrus leafminer control [*Phyllocnistis citrella*] (3X). Ethion 4EC (6 pt/acre) for broad mites [*Polyphagotarsonemus latus*] and snow scale [*Unaspis citri*] (2X), Copper fungicide (4 lb metallic) for melanose and foot and root rot (3X). sprayed orchard #3. Agrimek 0.15 EC + Petroleum oil 97% for *P. citrella* (10 fl oz/acre) (2X), Copper fungicide (4 lb metallic) (2X)

Data Analyses

For all the analyses, spider samples were pooled for each sample date and orchard. Abundance was calculated for all the identifiable adult species for spiders as well as for green lacewings, coccinellids, and ants. Spider species diversity among orchards was estimated using Simpson Index of Diversity (D) (Krebs 1989)

$1/D = 1/\sum pi^2$

Where 1/D = Simpson's reciprocal index
pi = proportion of spider species i in the community

Cluster analysis was done using the average linkage method (PROC CLUS, SAS Institute 1989). Data transformation ([log(mean weekly count+1)]) was calculated for cluster analysis.

Results and Discussion

Preliminary Survey of Predatory Arthropods

In general, the spiders significantly outnumbered the green lacewings, coccinellids, and ants (Figure 2-1). The density of green lacewing (*Chrysoperla rufilabris*) was significantly more than coccinellid (*Harmonia* sp.) and ants (*Myrmelachista* sp.). Nine families, 24 genera and 16 identifiable species of spiders were recorded (Table 2-2). Three families represented the web-building spiders, five families represented the hunting spiders, and one family represented the ambushers. Fourteen species i.e., *Araneus* sp., *Cyclosa* sp., *Eriophora ravilla*, *Gasteracantha cancriformis*, *Leucauge venusta*, *Neoscona arabesca*, *Theridion* sp., *Chiracanthium inclusum*, *Hentzia palmarum*, *Hibana velox*, *Lycosa* sp., *Phidippus regius*, and *Trachelas volutus*, occurred in all the orchards included in the sampling. *Conophista* sp. was found only in Orchard #1, *Acacesia hamata* in Orchard #2, and *Argiope catenulata* and *Metaphidippus vitis* in Orchard #3. *Latrodectus geometricus* and *Plexippus* sp. were found in Orchard #1 and #2 whereas *Lyssomanes viridis*,

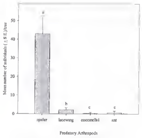

Figure 2-1 Abundance of predatory arthropods in lime orchards during summer, 1995 at Homestead, Florida. Vertical bars with the same letters are not significantly different according to DMRT ($P \leq 0.05$)

Tetragnatha sp ,and *Theridula* sp were found in Orchard #2 and #3 When the weekly count was averaged for the three orchards, five species of web-building spiders were represented by five or more individuals (Table 2-2) *Araneus* sp had a weekly mean count of 8 5±2 6, *Eriophora ravilla*, 8 8±1 9; *Gasteracantha cancriformis*, 9 3±2.7, *Leucauge venusta*, 7 2±2.1, and *Theridion* sp , 37 0±4 1 The highest frequency was recorded on *Theridion* sp. in all orchards (Figure 2-2) Among the hunting spiders, four species were recorded at five or more individuals namely, *Chiracanthium inclusum* (22.4±3 5), *Hentzia palmarum* (8 0±3 5), *Hibana velox* (39 4±7 7), and *Trachelas volutus* (23 8±3 8) The highest frequency was recorded for *Hibana velox* followed by *Trachelas volutus* and *Chiracanthium inclusum* (Figure 2-3)

The number of web building and wandering (hunters and ambushers) spiders collected from June to August 1995 is presented in Figure 2-4 The population of wandering spiders increased steadily from June 15 to July 7 with a sudden reduction in population density on July 15 followed by an increase on July 23 The population of the web-building spiders had a similar trend to that of the wandering spiders However, the web-building spider densities were relatively low in June until July 7, followed by a population increase on July 15 The population reached a plateau from July 23, decreasing after August 7

The results of this preliminary survey showed a rich spider community in lime orchards in Homestead, Florida. Therefore, for a successful integrated pest management strategy, proper identification of pests and their natural enemies is fundamental A simple spider identification key was developed to accomplish this identification objective (see Appendix A)

Among the web-building spiders, *Theridion* sp was the most abundant in lime orchards. *Theridion* sp preys on phytophagous mites (Putman 1967) and is also reported as one of the most abundant web-builders in apple orchards in Frelighsburg, Quebec

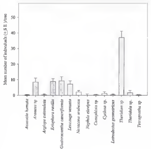

Figure 2-2. Abundance of the different species of web-building spiders in lime orchards at Homestead, Florida during June to August, 1995

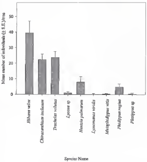

Figure 2-3 Abundance of the different species of hunting spiders in lime orchards at Homestead, Florida during June to August, 1995

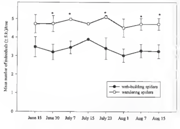

Figure 2-4 Weekly abundance of web-building spiders and hunting spiders collected from lime orchards at Homestead, Florida. Points with asterisk(*) indicate significant difference in the abundance between web-building and hunting spiders in each weekly sampling. Mean comparison is based on LSD ($P \leq 0.05$)

Table 2-2 Weekly count of spiders (representation by guild) collected in three lime orchards at Homestead, Florida.

Guild	Species	Orchard 1	Orchard 2	Orchard 3	Family
		Mean ± SE			
Web builder	*Acacesia hamata*	0.0 ± 0.0 b	8.5 ± 8.7 a	0.0 ± 0.0 b	Araneidae
	Araneus sp.	16.0 ± 3.9 a	5.4 ± 1.9 ab	4.0 ± 1.9 b	Araneidae
	Argiope catenulata	0.0 ± 0.0 a	0.0 ± 0.0 a	0.9 ± 1.5 a	Araneidae
	Eriophora antemulata	20.8 ± 3.2 a	5.0 ± 1.0 b	0.6 ± 0.9 c	Araneidae
	Gasteracantha cancriformis	12.3 ± 3.1 a	7.5 ± 2.4 a	8.2 ± 2.5 a	Araneidae
	Leucauge venusta	12.8 ± 2.4 a	5.9 ± 2.2 b	2.8 ± 1.0 b	Araneidae
	Metepeira sp.	0.2 ± 0.7 a	0.5 ± 0.7 a	0.4 ± 1.0 a	Araneidae
	Neoscona arabesca	5.1 ± 1.6 a	1.1 ± 0.9 b	0.4 ± 1.0 b	Araneidae
	Nephila clavipes	0.1 ± 0.6 a	0.1 ± 0.6 a	0.4 ± 0.9 a	Araneidae
	Conophista sp.	1.0 ± 1.4 a	0.0 ± 0.0 a	0.0 ± 0.0 a	Theridiidae
	Cyclosa sp.	1.8 ± 1.6 a	0.0 ± 0.0 a	1.1 ± 1.3 a	Theridiidae
	Latrodectus geometricus	0.2 ± 0.7 ab	0.8 ± 0.0 a	0.0 ± 0.0 b	Theridiidae
	Theridion sp.	42.5 ± 4.0 a	23.4 ± 2.2 a	45.1 ± 6.0 a	Theridiidae
	Theridula sp.	0.0 ± 0.0 a	3.5 ± 2.5 a	1.4 ± 1.9 a	Theridiidae
	Tetragnatha sp.	0.0 ± 0.0 a	0.1 ± 0.6 a	0.5 ± 0.9 a	Tetragnathidae
Hunters	*Hibana velox*	47.0 ± 5.5 a	42.4 ± 4.2 a	28.0 ± 3.6 a	Anyphaenidae
	Chiracanthium inclusum	29.1 ± 4.8 a	21.5 ± 2.9 a	16.5 ± 2.9 a	Clubionidae
	Trachelas volutus	32.2 ± 3.9 a	23.2 ± 4.0 a	16.1 ± 2.6 a	Corinnidae
	Lycosa sp.	1.4 ± 1.1 a	1.1 ± 1.0 a	0.9 ± 0.5 a	Lycosidae
	Lyssomanes viridis	0.0 ± 0.0 a	0.3 ± 0.7 a	0.4 ± 0.7 a	Salticidae
	Metaphidippus vitis	0.0 ± 0.0 a	0.0 ± 0.0 a	0.8 ± 1.4 a	Salticidae
	Phidippus regius	2.9 ± 1.6 a	4.0 ± 1.0 a	7.0 ± 2.6 a	Salticidae
	Plexippus sp.	0.6 ± 1.2 a	0.4 ± 0.9 a	0.0 ± 0.0 a	Salticidae
	Hentzia palmarum	5.3 ± 2.3 a	10.1 ± 2.7 a	6.6 ± 2.7 a	Salticidae
Ambushers	*Misumenops* sp.	0.5 ± 1.1 ab	0.7 ± 1.3 a	0.0 ± 0.0 b	Thomisidae

Means across rows followed by the same letters are not significantly different according to DMRT ($P \leq 0.05$).

Canada (Dondale et al. 1979). In citrus, a number of *Theridion* spp. was reported as the most common canopy web-building spiders. For instance, in California, Carroll (1980) found three *Theridion* spp. dominating the canopy of citrus trees. They built delicate sheet webs across a single leaf, catching primarily small flies, midges and psocids, but also some thrips, wasps, mites and aphids. Likewise *Theridion* sp. may also feed on various arthropod pests in lime orchards, possibly on phytophagous mites, thrips, and aphids.

The wandering spider group in lime orchards was dominated by three species of sac spiders, *Hibana velox* (Anyphaenidae), *Chiracanthium inclusum* (Clubionidae), and *Trachelas volutus* (Corinnidae). These sac spiders usually spend the day in loose silk nests in rolled leaves or other enclosed spaces. Carroll (1980) observed that sac spiders were the most abundant in California citrus orchards and wander rapidly at night over the citrus canopy, groping primarily for slow-moving or sessile prey i.e. thrips, mites, insect eggs, and lepidopterous larvae. After extensive laboratory tests of *Hibana* (=*Aysha*) sp. feeding on citrus thrips, Bravo-Mojica (1975 cited from Carroll 1980) concluded that this sac spider probably consumed a large number of thrips. However, Carroll (1980) also found that most species of spiders, except Clubionids and Anyphaenids, in citrus orchards feed primarily on innocuous species of insects, indicating that the impact of spiders on citrus pests is minimal. In Israel, Mansour et al. (1980a) demonstrated that on apple trees, removal of all sac spiders, primarily *Chiracanthium* sp., increased the survival of *Spodoptera* sp., (Noctuidae) caterpillars. Moreover, Wisniewska and Prokopy (1993) reported that Anyphaenid spiders fed on leafhopper nymphs and adults and on leafminer larvae. Our results indicated that in lime, *C. inclusum*, *H. velox*, and *T. volutus* were important mortality factors of CLM. Feeding tests in the laboratory revealed that these sac spiders attacked CLM even within the serpentine mines (Chapters 3 and 4).

The jumping spider, *Hentzia palmarum*, was also relatively common in the lime orchards. This species is a day hunter and was observed feeding on CLM larvae. This widely distributed species is commonly reported on commercial crops, including citrus, soybean, and cotton (Whitcomb et al. 1963a, b).

The spider population trend observed during the sampling period (June to August, 1995) suggests that the increase in population of hunting spiders and web-building spiders in June and July could probably be attributed to a higher population of arthropod prey during these months. For instance, Peña et al. (1996) reported high population peaks of citrus leafminer in June to July, 1995. It is therefore worthwhile to investigate the population of the important arthropod pests in lime during summer and correlate it to the population of the wandering and web-building spiders.

Comparison of Sampling Methods

The number of predators collected from lime orchards using three different sampling techniques is presented in Table 2-3. In all the orchards, the visual sampling method provided the highest number of spiders collected, followed by the shake-cloth method. A similar trend was observed for green lacewings, *Chrysoperla rufilabris*, except for Orchard #3, in which the shake cloth method collected more green lacewings than the visual method. The shake-cloth technique was found to be significantly more efficient for sampling ant populations than the visual technique followed by the DVAC sampling technique. For the entire sampling period, the coccinellid, *Harmonia* sp., population was low in all orchards. Ant densities, on the other hand, were found to be relatively high compared to coccinellids, particularly in Orchards #1 and #3 (Table 2-3). The spider species abundance of nine most commonly encountered species was calculated for all the sampling locations. The commonly encountered species consisted of four species of web building spiders and five species of hunting spiders. The web-building spiders included

Theridion sp (Theridiidae), *Gasteracantha cancriformis* (Araneidae), *Eriophora ravilla* (Araneidae), *Leucauge venusta* (Araneidae), the hunting spiders were *Hentzia palmarum* (Salticidae), *Chiracanthium inclusum* (Clubionidae), *Trachelas volutus* (Corinnidae), *Phidippus regius* (Salticidae), and *Hibana velox* (Anyphaenidae) Significant differences (P ≤ 0.05) for mean density of every spider species were observed among sampling methods except for *Eriophora ravilla* (Table 2-4) In general, there was significantly more individuals collected with the visual and shake cloth methods than with the DVAC suction method except for *Leucauge venusta* in which significantly more individuals were

Table 2-3 Number of predators collected in three lime groves using three different sampling techniques (Homestead, FL, Summer 1996)

Location	Sampling Technique	Predators			
		Spiders	Lacewings	Coccinellids	Ants
Orchard #1	Visual	10.5 a	0.58 a	0.03 ab	0.67 b
	Shake - Cloth	7.0 b	0.03 b	0.08 a	2.48 a
	DVAC	1.8 c	0.03 b	0.00 b	0.11 b
Orchard #2	Visual	10.7 a	5.6 a	0.08 a	0.02 b
	Shake - Cloth	7.3 b	1.2 b	0.02 a	0.72 a
	DVAC	1.3 c	0.5 b	0.02 a	0.02 b
Orchard #3	Visuals	9.4 a	0.76 a	0.24 a	0.20 b
	Shake - Cloth	10.8 a	0.04 b	0.27 a	3.30 a
	DVAC	2.7 b	0.07 b	0.13 a	0.18 b

Number indicated average count for 5 flushes on 10 trees

Means in columns for each orchard followed by the same letters are not significantly different According to DMRT (P ≤ 0.05)

collected using the DVAC Analysis of spider abundance was made on the nine most abundant spider species mentioned above. The sampling method had a significant effect (P ≤ 0.05) on mean density of every spider species during the study (Table 2-4) Three were more hunting spiders collected using visual and shake cloth methods than using the DVAC (Figure 2-5) whereas more web-building spiders were collected using the DVAC

Table 2-4 Abundance of commonly encountered spiders in lime orchards using visual, shake-cloth, and DVAC sampling methods

Guild	Species	Mean weekly count (± S.E.)		
		Visual Method	Shake-Cloth	DVAC
Web-builders	*Theridion* sp.	13.0 ± 3.0 a	23.5 ± 5.5 a	4.0 ± 1.3 b
	Gasteracantha cancriformis	1.6 ± 0.5 b	3.1 ± 0.9 b	5.1 ± 1.0 a
	Eriophora ravilla	1.2 ± 0.3 a	1.4 ± 0.5 a	0.4 ± 0.2 a
	Leucauge venusta	0.5 ± 0.2 b	3.2 ± 0.9 b	4.7 ± 0.9 a
Hunters	*Hentzia palmarum*	3.0 ± 1.0 ab	5.2 ± 1.0 a	1.9 ± 0.5 b
	Chiracanthium inclusum	10.0 ± 2.2 a	0.6 ± 0.3 b	0.1 ± 0.1 b
	Trachelas volutus	10.0 ± 2.4 a	2.8 ± 0.7 b	0.0 ± 0.0 b
	Phidippus regius	1.5 ± 0.4 ab	3.6 ± 0.9 a	0.6 ± 0.2 b
	Hibana velox	40.7 ± 3.7 a	4.7 ± 0.9 b	0.3 ± 0.1 b

Means across rows followed by the same letters are not significantly different according to DMRT ($P \leq 0.05$)

except for *Theridion* sp., which more frequently found using the visual and shake cloth methods The sac spiders, *H. velox*, *C. inclusum*, and *T. volutus* were rarely captured using the DVAC and shake cloth methods Results from this study suggest the higher efficiency of visual and shake-cloth methods in sampling spiders in lime orchards compared to DVAC suction method The retreating habits of the different spider species in lime orchards may explain the difference in the efficiency of the three sampling methods. For instance, *Theridion* sp., which was the most abundant web-building spiders in lime orchards, hide themselves in a delicate sheet web constructed on leaf adaxial surfaces usually on the edge of the major leaf veins (Carroll 1980) and also on branch or stem crevices (personal observation) Shaking the plants will easily dislodge *Theridion*

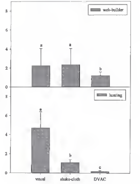

Figure 2-5 Comparison of the abundance of web-building and hunting spiders collected by the different sampling methods. Vertical bars with the same letter indicate no significant difference according to DMRT ($P \leq 0.05$)

sp from the retreat nest The sheet web is also easily noticeable by visual examination The DVAC suction machine did not have easy access to retreat locations of *Theridion* sp. Wandering spiders, *C inclusum*, *H velox*, and *T volutus* retreat in a concealed manner They usually are inside folded leaves glued with strong sticky silk. Shaking or suctioning the plant will not easily loosen this silk, however, the sticky glued leaves are easily noticeable. Thus, visual examination has an advantage over shake-cloth and DVAC suction methods in sampling these species of spiders.

Spiders in Sprayed and Nonsprayed Orchards

In general, the number of predatory arthropods was significantly higher in the nonsprayed orchards than in the sprayed ones except for coccinellids (Figure 2-6). Ten spider families represented by 24 species were captured during this study (Table 2-5)

Families Anyphaenidae, Clubionidae, Corinnidae, and Theridiidae were the most numerous followed by Araneidae and Salticidae. Families Lycosidae, Lyssomanidae, Tetragnathidae, and Thomisidae were also present but were not very common. Abundance of the different species of spiders was computed by dividing them into two guilds the web building and the hunting spiders. Among the web building spiders, *Theridion* sp was the most abundant species in all the orchards whereas for the hunting spiders, three species of sac spiders, *Hibana velox*, *Chiracanthium inclusum* and *Trachelas volutus* and one species of jumping spider, *Hentzia palmarum* were the most abundant. These spider species were recorded at more than 10 individuals per sampling period in all the orchards.

Numbers of hunting spiders were significantly higher in nonsprayed than in sprayed orchards, for the web-building spiders There was no significant difference with the spider abundance between the sprayed and nonsprayed orchards (Figure 2-7) The Simpson diversity index (SDI) for web-building spiders in nonsprayed and sprayed orchards were 9.1 and 7.7, respectively. For the hunting spider group, the calculated SDI was 4.0 in the nonsprayed orchards and 3.3 in the sprayed orchards. The calculated diversity index showed that there were more species for both web-building and hunting spider groups in nonsprayed orchards than in sprayed ones (Table 2-5). Cluster analysis revealed two groupings of orchards in terms of the densities of web building

Table 2-5 Abundance and diversity of spiders in nonsprayed and sprayed orchards

Guild	Species	Family	Nonsprayed		Sprayed	
			Abundance (mean±S.E)	Diversity Index	Abundance (mean±S.E.)	Diversity Index
Web-builders	*Theridion sp.*	Theridiidae	21.3 ± 2.9	9.1	33.7 ± 4.4	7.7
	Coleosoma blandum	Theridiidae	2.5 ± 2.3		2.5 ± 2.0	
	Gasteracantha cancriformis	Araneidae	9.8 ± 2.5		11.9 ± 2.8	
	Eriophora ravilla	Araneidae	4.0 ± 1.9		11.5 ± 2.8	
	Leucauge venusta	Araneidae	8.9 ± 2.3		9.2 ± 2.5	
	Neoscona arabesca	Araneidae	2.2 ± 0.9		5.5 ± 1.5	
	Latrodectus mactans	Theridiidae	0.8 ± 0.9		0.2 ± 0.6	
	Araneus sp.	Araneidae	6.5 ± 2.0		7.5 ± 3.7	
	Metepeira sp.	Araneidae	0.5 ± 0.7		0.3 ± 0.7	
	Cyclosa sp.	Araneidae	1.3 ± 0.8		1.3 ± 1.5	
	Tetragnatha sp.	Tetragnathidae	0.2 ± 0.6		0.0 ± 0.0	
	Acacesia hamata	Araneidae	0.7 ± 0.7		0.0 ± 0.0	
	Metacyrba sp.	Araneidae	0.5 ± 0.9		0.0 ± 0.0	
	Acanthepeira	Araneidae	0.2 ± 0.6		0.0 ± 0.0	
	Nephila clavipes	Araneidae	0.2 ± 0.6		0.2 ± 0.6	
Hunters	*Hentzia palmarum*	Salticidae	14.7 ± 3.5	4.0	14.2 ± 3.4	3.3
	Hibana velox	Anyphaenidae	66.7 ± 4.3		33.5 ± 6.6	
	Trachelas volutus	Corinnidae	37.1 ± 3.2		25.1 ± 4.5	
	Misumenops sp.	Thomisidae	2.1 ± 1.3		0.7 ± 0.9	
	Phidippus regius	Salticidae	4.5 ± 1.7		4.7 ± 1.2	
	Lyssomanes sp.	Lyssomanidae	0.2 ± 0.9		0.0 ± 0.0	
	Chiracanthium inclusum	Clubionidae	36.5 ± 3.1		23.0 ± 4.5	
	Plexippus sp.	Salticidae	1.2 ± 1.2		0.2 ± 0.6	
	Lycosa sp.	Lycosidae	1.3 ± 1.0		1.3 ± 1.1	

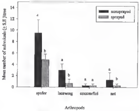

Figure 2-6 Difference in the abundance of spiders and other insect predators in nonsprayed and sprayed orchards Bars with with the same letters are not significantly different according to DMRT ($P \leq 0.05$)

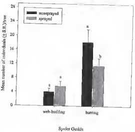

Figure 2-7 Difference in the abundance of the two spider guilds in nonsprayed and sprayed orchards. Bars with the same letter are not significantly different according to DMRT ($P \leq 0.05$)

and hunting spiders in each orchard. For the web building spiders, the highest similarity was between orchard #3 and orchard #5 (CL [cluster] 1) (Figure 2-8), which clustered first at an average distance of 2.0, orchard #2 and orchard #6 also clustered independently with an average distance of 3.9 (CL2). Two distinct clusters or groupings are evident: orchard#1, orchard #2, and orchard #6 as the first group and orchard #3, orchard #4, and orchard #5 as the second group. For the hunting spiders, two independent clusters were obtained (Figure 2-9), one for orchard #2 and orchard #3 and another one for orchard #4 and orchard #6, with an average distance of 1.6 (CL1) and 2.3 (CL2), respectively. Similar to the grouping of web-building spiders, two distinct groups or clusters were identified. However, the orchards included in the groupings differed from the web-builders group. The first group consisted of orchard #1, orchard #2 and orchard #3. The second group included orchard #4, orchard #5, and orchard #6. The unifying factor for the orchard groupings was the application of the pesticides. For the hunting spiders, the first group consisted of orchards that were sprayed whereas in the second group, the orchards were not sprayed. For the web-building spiders, the group consisted of mixed sprayed and nonsprayed orchards. There was no clear common factor in the two orchard groupings. It is evident from the result of the spider abundance, diversity, and cluster analysis that the hunting groups are probably more affected by pesticides.

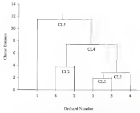

Figure 2.8 Dendogram of web-building spider abundance based on average linkage cluster (CL) analysis. The analysis includes all sites.

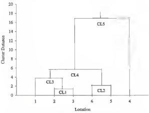

Figure 2.9 Dendogram of hunting spider abundance based on average linkage cluster analysis. The analysis includes all sites

CHAPTER 3
PREDATION BY THE THREE SPECIES OF SAC SPIDERS ON CITRUS LEAFMINER, *PHYLLOCNISTIS CITRELLA* (LEPIDOPTERA. GRACILLARIIDAE)

Introduction

A great deal of research has focused on species of hymenoptera that parasitize the citrus leafminer (CLM). *Phyllocnistis citrella* Stanton (Knapp et al. 1995, Heppner 1995, Burgeous & Constantin 1995). Some of the parasitoid species cause mortality by feeding externally on their host (R. Duncan, personal communication) and their effect can be confused with that caused by predators, which are also potential control agents for *P. citrella* (Browning 1994, Browning & Peña 1995, Amalin et al. 1995, Zhao 1989, Zhang et al. 1994, Argov & Rossler 1996). Two species of lacewings, *Ancylopteryx octopunctata* and *Chrysopa boninensis*, have been effective against CLM in the Guangzhou area of South China. Larvae of *A. octopunctata* feed only on eggs, larvae, and pupae of the CLM whereas *C. boninensis* feeds on all stages (Zhang et al. 1994). *Chrysopa boninensis* larvae can eat an average of 149 CLM during development at temperatures near 95°F, but it is less effective when temperatures are below 59°F (Chen et al. 1989). In Florida and Honduras, *Chrysoperla rufilabris* larvae have been observed feeding on CLM larvae. In a preliminary experiment, supplemental releases of lacewing larvae significantly reduced the number of CLM per tree during three weeks following release (Browning & Peña 1995). Ants were also found feeding and removing CLM larvae in South China (Huang et al. 1989). Spiders were also observed in the field to prey upon the CLM (Argov & Rössler 1996).

Few studies have been made to identify indigenous generalist spiders (Amalin et al. 1995) or assess their effects on CLM densities. The objectives of this study are to identify the species of spiders feeding on CLM and to evaluate their efficiency as predators of CLM under laboratory, greenhouse, and field conditions. Preliminary observations on the analysis of the prey remnants inside the gut of the spiders is presented and discussed. The method is based on the detection of prey enzymes in homogenates of the predator after polyacrylamide gel electrophoresis. The main purpose of this study is to develop a system for assessing the efficiency of spiders on CLM control in nurseries and orchards.

Materials and Methods

Laboratory feeding test

Five species of orb-weaving spiders, *Gasteracantha cancriformis*, *Leucauge venusta*, *Nephila clavipes*, *Neoscona arabesca*, and *Eriophora ravilla*, three species of space-web spiders, *Theridion sp.*, *Theridula sp.*, and *Coleosoma floridanum*, and five species of hunting spiders, *Chiracanthium inclusum*, *Hentzia palmarum*, *Hibana velox*, *Phidippus regius*, and *Trachelas volutus* collected from an experimental lime orchard at Tropical Research and Education Center (TREC), Homestead, Florida were included in the feeding test. Immature spiderlings from each species were placed individually in a 15mm x 100mm diameter petri dish lined with a gel substrate (400 mg agar, dissolved in 1000 ml of distilled water, with 2 mg Benlate dissolved in 20 ml acetone and autoclaved at 1.1 kg cm $^{-2}$ for 15 min) (Figure 3-1). Portions of leaf containing five second-instar *P. citrella* larvae were placed in the petri dish. The containers were kept in an incubator maintained at 27°C, 12L:12D, and 80% RH. During three consecutive days, the larvae were removed daily from the containers and replaced with fresh ones. On these containers, the number of larvae killed was counted. The experiment was repeated three times on three different dates.

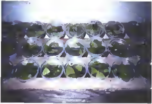

Figure 3.1 Experimental set-up for the laboratory feeding test

Feeding efficacy test

Laboratory studies. The susceptibility of *P. citrella* to *C. inclusum*, *H. velox*, and *T. volutus* was tested in the laboratory. Laboratory-reared second and third spiderling instars of *C. inclusum*, *H. velox*, and *T. volutus* were placed in petri dishes with 10 second instar *P. citrella* larvae following the methodology specified above. Petri dishes were kept in the incubator at 27°C, 12L:12D photoperiod, and 80% RH. Mortality of *P. citrella* was recorded every three days for two weeks. Each treatment was replicated three times.

Greenhouse studies. Predation of *C. inclusum*, *H. velox*, and *T. volutus* on *P. citrella* larvae was measured under greenhouse conditions using branch cages. Cages consisted of a modified 2-liter soft drink bottles of clear polyethyleneterethylate (PET) with fabric sleeves attached in both ends (Figure 3-2). Cages were 240mm x 120 mm, and enclosed one branch of a half-gallon potted lime plant. All branches used in this study had 15.0±1.3 leaves to produce a standard infestation of 20 first and second instar larvae of *P. citrella* per cage. Any other insect or mite species were hand-removed from the cage. This was done to keep the area of discovery constant during the experiment period and to prevent other factors from interfering with the parameters being examined.

A single 3rd spider nymphal stage was placed into each cage and dead CLM larvae counted one week after exposure. Control cages contained *P. citrella* but no spiders and other predators. Each treatment was replicated three times. The temperature fluctuated daily from 25 to 27°C with 70.0% ± 9.6 RH. Mean weekly predation rates were recorded and compared between prey regimes by one way analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT).

Outdoor cage studies. Research was conducted during July, 1998 and August, 1998 at the Tropical Research and Education Center, Homestead, FL. Rates of predation

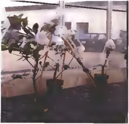

Figure 3.2 Experimental set-up for the feeding efficiency test of the three species of sac spiders on CLM under the greenhouse conditions.

of *Hibana velox* on first, second, third larval instars and prepupal stage of *P. citrella* were measured using field cages. Cages were constructed of nylon mesh screen (91cm wide x 91cm long x 122cm high) supported on PVC frames. One side of the cage had a slit opening, which was provided with a zipper to close and open the cage (Figure 3-3). The cages enclosed two-year old potted lime plants. All plants were previously infested with CLM to produce a standard infestation per plant. Only 1st, 2nd, and 3rd instar larvae were retained and all other *P. citrella* stages removed. This was done to keep the prey numbers constant throughout the experiment. Before the plant was introduced into the cage, the plants were shaken vigorously to dislodge any resident arthropods, which were then removed. Each pot inside the cage was placed on a plastic pot container with water. This was done to avoid other predators (i.e. ants), which can crawl at the bottom slit of the cage to get into the plants.

Two different experiments were conducted to determine spider predation rates. For the two experiments, fourth spiderling instar of *H. velox* previously fed an artificial diet (see Chapter 5) was used. In the first experiment, 0, 1, 5, 10, and 25 *P. citrella* larvae were placed into each cage and a single spider added to each cage. Each treatment was replicated three times. Control cages contained prey but not predators. In the second experiment, 25 -1st and 2nd larval instar of *P. citrella* were placed into each cage and 1, 2, and 3 fourth instar spiderling *H. velox* were introduced per cage. Cages were inspected twice a week for two weeks. Dead CLM were recorded and removed. Control cages contained prey but no predators. Each treatment was replicated three times. Percent mortality was calculated as number of dead CLM divided by the total number of CLM in each plant. Mean weekly predation rates were compared between predator regimes by analysis of variance and differences among treatments were compared by Duncan's Multiple Range Test (DMRT).

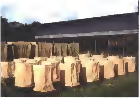

Figure 3.3: Experimental set-up for the feeding efficiency test of *H. velox* on CLM using outdoor cages

Gut Content Analysis

The prey remnants inside the gut of *Chiracanthium inclusum*, *Hibana velox* and *Trachelas volutus* were detected by Polyacrylamide gel electrophoresis (PAGE). The method is based on the detection of prey enzymes in homogenates of the predator after PAGE and then stained for esterase activity.

Spiders and CLM samples Fourth-nymphal spiderlings of *C. inclusum*, *H. velox*, and *T. volutus* were obtained from the laboratory culture. For rearing conditions, see Chapter 5. Samples of CLM larvae were obtained from field collections. Homogenates were obtained from spiders fed with five 2nd larval instar of CLM, spiders fed with artificial food medium, and 2nd larval instar of CLM. Spiders were squashed individually in a 5-10μl of maceration fluid (tris/EDTA/borate buffer with 0.2% TritonX-100 and 10% sucrose) in a shallow pit in a perspex plate by means of a glass rod. A similar maceration procedure was used for CLM larvae except that numbers of larvae varied from 1, 2, 5, to 10 CLM in different homogenate samples. This range of larval densities was used in order to determine the difference in the intensity of esterase bands with varying numbers of CLM larvae. For each sample, 20 μl homogenate was dispensed with the aid of loading tip to the sample holders that were positioned on top of the gel.

Electrophoresis Electrophoresis was carried out as described by Murray and Solomon (1978) and by Solomon et al. (1985) with some modifications. Polyacrylamide slab gels (see Appendix B for detailed composition) with a total gradient concentration of 5-28% and a cross-link gradient of 2.5-6.2% (Margolis & Wrigley 1975) were prepared between two glass plates with the aid of gel gradient maker. A tris/EDTA/borate (TEB) buffer pH 8.3, to which 0.2% w/v Triton X-100 was added, was used as the gel buffer

The running buffer was also TEB without Triton X-100. The samples were run to endpoint for 20 h at 200 volts.

After electrophoresis, gels were incubated in a medium containing 30mM 1-naphthyl acetate and 0.2% Fast Blue RR Salt in 0.2 M phosphate buffer, pH 6.0 in order to stain proteins with esterase activity. Conclusions about the identity of prey remnants inside the gut of predators were drawn by visual comparison of esterase patterns of the artificially fed spiders and CLM fed spiders.

Results and Discussion

Feeding test

Among the three tested spider guilds, only the hunting spiders were confirmed to feed on CLM larvae and in some cases prepupae (Table 3-1). The four species of

Table 3-1 Result of the feeding test for commonly encountered spider species in lime orchards on CLM larvae

Taxa/Guild	Species (n = 10)	CLM Association
Orb-weaving spiders	*Eriophora ravilla*	no
	Gasteracantha cancriformis	no
	Leucauge argyra	no
	Neoscona arabesca	no
	Nephila clavipes	no
Space-web spiders	*Coleosoma floridanum*	no
	Coleosoma acutiventer	no
	Theridion sp.	no
Hunting spider	*Chiracanthium inclusum*	yes
	Hentzia palmarum	yes
	Hibana velox	yes
	Misumenops sp.	no
	Phidippus regius	no
	Trachelas volutus	yes

hunting spiders were three species of sac spiders, *Chiracanthium inclusum* (Clubionidae) (Figure 3-4), *Trachelas volutus* (Corinnidae) (Figure 3-5), *Hibana velox* (Anyphaenidae) (Figure 3-6), and one jumping spider, *Hentzia palmarum* (Salticidae). All of the species of spiders attacked CLM larvae within the mines by puncturing the mines and then sucking the body fluid of the larvae or by making a hole in the mines, pulling the larvae out and then feeding on the body fluids.

Feeding efficiency test

Laboratory studies

Feeding efficiency test under laboratory conditions was conducted on 3 species of hunting spiders, *C. inclusum*, *H. velox*, and *T. volutus*. The jumping spider, *H. palmarum*, was not included in the test because very few eggs were available and the spiderling emergence was very low. Results of the feeding efficiency tests are shown in Table 3-2. The second spiderling instar of *H. velox* and *T. volutus* consumed significantly more CLM larvae than *C. inclusum*. The third spiderling instar *H. velox* consumed significantly more CLM larvae than *C. inclusum* and *T. volutus* (Table 3-2). Under laboratory conditions, the predation rate of the three species of sac spiders can be ranked as follows *H. velox* > *C. inclusum* > *T. volutus*. This finding suggests that *H. velox* is a more efficient predator than *C. inclusum* or *T. volutus*. Nevertheless, the presence of these three species of spiders as well as the jumping spider, *H. palmarum*, should give a higher degree of predation on CLM population than a single predator in the orchard.

Greenhouse studies

The result on the predation rate of the three species of sac spiders on CLM larvae under greenhouse conditions is presented in Figure 3-7. The trend or the ranking of

Table 3-2 Efficacy of the second and third nymphal spiderling stages of the three species of spiders on CLM larvae

Spider Species	Percent CLM mortality by different spiderling nymphal stages	
	second nymphal stage	third nymphal stage
Chiracanthium inclusum	28.5 b	43.5 b
Hibana velox	58.3 a	83.3 a
Trachelas volutus	56.3 a	39.7 b

Means followed by the same letters within a column are not significantly different ($P \leq 0.05$) according to DMRT

predation rate is similar to the result obtained from the laboratory efficiency test. *Hibana velox* consumed more CLM larvae than *C. inclusum* and *T. volutus*. This result, as well as the result under laboratory conditions, confirmed our hypothesis that sac spiders are probably the most promising natural enemies of CLM in lime orchards. Previous feeding tests conducted on related species of sac spiders on other lepidopterous pests gave similar results. For instance, Carroll (1980) reported that sac spiders in the families Clubionidae and Anyphaenidae preyed on a number of important arthropod pests such as Lepidoptera, mites, and thrips and concluded that sac spiders contribute to control of lepidopterous pests in California citrus orchards. Moreover, an experiment in Israel on apple trees demonstrated that when all sac spiders, primarily *Chiracanthium* spp., were removed from the trees, the survival of *Spodoptera* sp. (Noctuidae) caterpillars hatching from egg masses was very high whereas if the spiders were left on the trees very few caterpillars survived. Corrigan & Bennett (1987) also reported that *C. mildei* sought out apple trees infested with spotted tentiform leafminer, *Phyllonorycter blancardella*. Other species of sac spiders, particularly members of the Anyphaenid family, were found feeding and reducing the tentiform leafminer larvae on apple trees

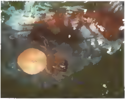

Figure 3-4 *Chiracanthium inclusum* feeding on CLM larva.

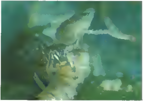

Figure 3-5 *Hibana velox* feeding on CLM larva.

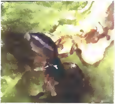

Figure 3.6 *Trachelas volutus* feeding on CLM larva

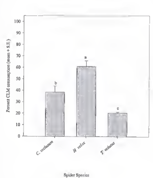

Figure 3-7 Predation rate of *C. inclusum*, *H. velox*, and *T. volutus* on CLM larvae under greenhouse conditions. Bars followed by the same letters are not significantly different according to DMRT ($P \leq 0.05$)

Outdoor cage studies

Experiment 1. The results of the field cage experiment indicated that as the density of its prey increases, the number of prey consumed by *H. velox* also increases (Table 3-3). The functional response curve of *H. velox* to prey density (Figure 3-8) is essentially similar to the sigmoid curve, characteristic of the functional responses of various predators (Holling 1961, Huffaker et al. 1971). The response obtained is also similar to the sigmoid curve described for *Chiracanthium mildei* (Araneae: Clubionidae) preying on different densities of *Spodoptera littoralis* (Mansour et al. 1980a, b) and for *Philodromus rufus* (Araneae: Thomisidae) consuming various densities of *Drosophila* (Haynes & Sisojevic 1966).

Table 3-3 Average number of prey consumed per *Hibana velox* provided with different densities of 1st and 2nd instar larvae of *P. citrella*

Predator:Prey Ratio	Mean weekly prey consumed/predator ± S.E.
1:1	1.0 ± 0.0 c
1:5	3.7 ± 0.6 c
1:10	5.3 ± 3.2 b
1:25	13.3 ± 2.3 a

Mean followed by the same letters are not significantly different (P≤0.05) according to DMRT

Experiment 2. Significantly more CLM larvae were consumed when two to three spiders were placed inside each cage (Figure 3-9). There is a possibility that the activity of the predator may be affected by predator density if predators interact (Burnett 1958). The predator functional response in relation to prey density may be an adequate indicator of

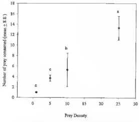

Figure 3-8 Effect of density of citrus leafminer larvae on the number consumed upon exposure to *Hibana velox*. Points with the same letters are not significantly different according to DMRT ($P \leq 0.05$)

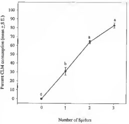

Figure 3-9 Effect of different numbers of spiders on the percent CLM consumption. Points with the same letters are not significantly different according to DMRT ($P \leq 0.05$)

predatory potential It is evident from the results of this experiment that as the number of spider increased, the prey consumption also increases. Future investigations should determine the best predator-prey ratio for managing the population of CLM

Gut content analysis through electrophoresis

Prey as well as predator species have a characteristic esterase pattern No esterase was obtained from the *C inclusum* and *T volutus* fed with artificial medium (Figure 3-10, wells 3 to 5); however, *H velox* that fed on the artificial medium gave one esterase band, which is different from the CLM esterase in having lower molecular weight than the CLM esterase. The esterase obtained on *C. inclusum* fed with CLM larvae in the laboratory was similar to the esterase of CLM Similarly, a single esterase band was obtained from *H. velox* that fed on CLM and this band also seems to be identical to the CLM esterase (Figure 3-11, well 9) No esterase activity was obtained from *T volutus* that fed on CLM larvae.

The specific esterase activity patterns allow in many cases the identification of prey remnants inside the predator gut (Van Der Geest & Overmeer 1985). After electrophoresis and staining for esterase activity, the CLM larvae and prepupae showed only one esterase (Figures 3-10 and 3-11) There was a difference in the intensity of the esterase bands on the different numbers of individuals included in each macerated sample. The intensity increases as the number of individuals per sample increases (Figures 3-10 & 3-11). This difference in intensity could possibly be used to quantify the number of prey consumed by the predator The results of this experiment are in conformity with the result by Murray & Solomon (1978) on the esterase pattern of *Panonychus ulmi* (Koch), the European red spider mite On the contrary, Dicke & DeJong (1988) have obtained several esterases also on *P ulmi* Only the CLM esterase appears to have been expressed in

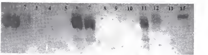

Figure 3-10 Esterase pattern of CLM, *C inclusum* and *T volutus* The identity of the different wells are as follows

1 – standard
2 – 2 *C. inclusum* fed with CLM in the lab
3 to 5 – 2 *C inclusum* artificial diet fed
6 – 10 CLM prepupae
7 – 5 CLM prepupae
8 to 9 – 2 *T volutus* fed with CLM in the lab
10 – 2 *T volutus* fed with artificial diet
11– 10 CLM larvae
12– 5 CLM larvae
15– 2 CLM larvae

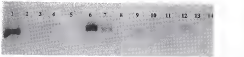

Figure 3-11 Esterase pattern of CLM and *H velox* The identity of the different wells are as follows

1– standard
2 to 4 – 2 *H velox* artificially fed
5 – blank
6 – 10 CLM prepupae
7 – 5 CLM prepupae
8 – blank
9 – 2 *H velox* fed with CLM in the lab
10 – 10 CLM larvae
11 – 5 CLM larvae
12 – 2 CLM larvae
13 – 1 CLM
14 – blank

spiders that fed on CLM, however, this result should be confirmed by doing more electrophoresis runs with a higher number of specimens in a macerated sample. Moreover, using a field-collected predator, a difficulty may arise in the identification of prey as not all esterases of a prey may be found in the gut of a predator. Certain esterases may be localized in tissues that are not ingested, complicating the identification of the prey for field collected specimens. It is necessary to co-electrophorese all suspected prey species with the predators on the same gel. Moreover, the use of other enzymes i.e. fumarate hydratase, glucose-6 dehydrogenase, and hexokinase must also be considered in order to look for a more stable enzyme that will be used for gut content analysis.

CHAPTER 4
PREDATORY BEHAVIOR OF THREE SPECIES OF SAC SPIDERS ATTACKING CITRUS LEAFMINER

Introduction

Great differences exist among spiders concerning the ways in which they obtain their prey. While, some spiders stalk their prey and others ambush it, most spiders trap their prey by snares and a few live as commensals. Spiders destroy their prey by means of venom secreted by a pair of glands in the cephalothorax. The ducts from these glands open on each side through a minute pore located near the tip of the claw of the chelicerae.

Prey catching strategies have been thoroughly studied in web building spiders (Foelix 1996). For instance, the sheet web spider (family Agelenidae) hides in its funnel-shaped retreat nest and rushes out only when the prey has been trapped in the web. Members of the family Linyphiidae construct a horizontal sheet web with vertical threads that serve as trapping lines for insects. Once the prey is trapped by the threads, the spider shakes the web until the victim falls onto the sheet, then bites through the web and pulls down the victim. Some web building spiders (i.e. theridiids) produce threads with glue droplets, that trap and glue the insect to the broken thread becoming progressively more entangled while freeing itself. The alerted spider quickly climbs down and throws more sticky threads over the victim before biting it. The various groups of orb-weaving spiders exhibit three related strategies of prey capture. Strategy 1 – seize with chelicerae - pull out of web - carry in chelicerae - wrap at hub and secure to web – feeding, i.e., *Nephila* spp., Strategy 2 – bite - wrap in web - cut out of web - carry on thread or carry on chelicerae - wrap at hub and secure to web – feeding, i.e., *Nephila* spp. and Strategy 3 – wrap - bite -

cut out of web and carry on thread or cut out of web and carry on chelicerae - wrap at hub and secure to web – feeding, i.e. *Araneus* and *Argiope*

The wandering spiders do not rely on a snare, but most locate and overpower their prey directly. Among the more familiar examples of wandering spiders are the wolf spiders (Lycosidae), the jumping spiders (Salticidae), most of the crab spiders (Thomisidae), and the two-clawed foliage spiders (Clubionidae, Anyphaenidae). These spiders run in search of their prey and pounce upon it when an opportunity arises. Wandering spiders exemplified by lycosids or wolf spiders are reported to actively hunt for their prey (Savory 1926, Comstock 1948, Bristowe 1971) and are equivalent to Schoener's type II predator, expending time and energy on searching (Foelix 1996). Hunting spiders spend some of their time stationary in one place and may in fact adopt a sit and wait strategy. The entire prey capture for wandering spiders passes through the following stages: locating the prey, turning toward the victim and grasping it with the tips of the front legs, pulling the prey to the chelicerae and biting (venom injection), releasing the grasp with the legs and holding the prey with the chelicerae, fastening of some silk thread over the immobilized prey, and then feeding. Wandering spiders may locate their prey either by visual cues or by vibration, depending on the species. Classical examples of visually guided predators are the jumping spiders. They have highly developed main eyes that can analyze shapes, and can even recognize motionless prey (Jackson & Tarsitano 1993). Blind spiders, like the clubionids and related species, rely on the vibration of the substrate or immediate contact with a victim to elicit direct catching movements.

The three species of hunting spiders found feeding on CLM larvae and prepupae, belong to the group of spiders with poor vision [Chapter 3]. Most likely their prey capture depends greatly on the substrate vibration. In this chapter, the predatory behavior of three species of hunting spiders [*Chiracanthium inclusum* (Clubionidae), *Hibana velox* (Anyphaenidae) and *Trachelas volutus* (Corinnidae)] attacking CLM is investigated

This study has three objectives. 1) to determine the time of feeding activity, 2) to investigate the predation strategy, and 3) to know the developmental stages of spiders actively feeding on CLM.

Materials and Methods

Time of feeding activity

Feeding times of the three hunting spiders were determined from observations over a 24-hour period. A petri plate (10.5 cm diam x 2.0 cm high) was used as the experimental arena. Leaves of lime (*Citrus aurantifolia*) with five CLM larvae within the serpentine mines were placed in each petri plate. A single fourth-nymphal-stage spiderling was placed in each arena that was lined at the bottom with moistened filter paper to retain the freshness of the leaves. The experimental set-up was replicated three times for each of the three spider species, for a total of nine separate plates. All the petri plates were placed in an incubator with constant temperature (27°C) and relative humidity (80%), and a 12-h photoperiod.

Observations of spider activities were made every 15 min during the photophase and scotophase, using a portable red light with an intensity of 5.0 Lux.

Predatory strategy

Observations of spider activity were done by videotaping, using a video time lapse cassette recorder (Panasonic Model AG-6730). The three species of hunting spiders included in this experiment were placed separately in a small petri plate (3.5 cm diam. x 0.5 cm high). The petri plate was provided with 5 CLM second instar larvae on lime leaves still within the serpentine mines. The petri plate was positioned under the video camera and the video machine was set to 16-hour recording. The video taping was conducted in a room with all the lights off starting at 6:00 in the evening until 7:00 the following morning To have a clear view of the predatory activity, red lights (5 0 Lux intensity) were aimed at the shooting arena around the petri plate. The following data were gathered retreat period (no locomotion, no body movement, the spider remained inside the retreat nest), searching time (locomotory action toward prey), handling time (often indicated by a period during which the spider started to attack the prey and lasted until prey was consumed) The number of CLM consumed was verified the following morning by counting the number of dead CLM under a microscope

Active feeding stages

To determine spider developmental stages feeding on CLM, the three species of spiders were reared from first nymphal stage to adult stage using CLM solely as their food Ten CLM second instar larvae still within the serpentine mines on lime leaves were placed in each petri plate (10 5 cm diam x 2 5 cm high) Individual first nymphal-stage spiderlings were introduced into each petri plate Ten spiders per species were included in the experiment. Dead CLM larvae were counted every other day, and after the mortality reading, new CLM larvae were added to each petri plate to keep the number of CLM constant The molting period was noted for each spider to determine the developmental stages

Results and Discussion

The mean duration of locomotory activity for each species was grouped in six 4-hour time intervals and these values are plotted in Table 4-1 Our observations confirmed that *C inclusum*, *H velox*, and *T volutus* are all nocturnally active (Figure 4-1)

Table 4-1 Activity pattern of the three species of hunting spiders in six 4-hour intervals

Time Interval	Duration (hours)
	Diurnal Observation
1	06.00 - 10 00
2	10 00 - 14 00
3	14 00 - 19 00
	Nocturnal Observation
4	19 00 - 22 00
5	22 00 - 01 00
6	01 00 - 06 00

The onset of the locomotory activity for *C. inclusum* and *H velox* was at the beginning of interval 4, which was about one hour into the scotophase. *Trachelas volutus*, on the other hand, showed some locomotory activity 4 hour into photophase. The observed daytime activity of *T volutus* was very short, lasted only 30 minutes, followed by a retreat period of about 7 hours. The peak of locomotory activity for the three species was at intervals 4 and 5 The locomotory activity was reduced at the end of interval 6 These observations suggest that *C. inclusum* and *H velox* are strictly nocturnally active hunters *Trachelas volutus* is primarily a nocturnal hunter but could also be active during the day

These three species of spiders belong to a group of spiders with poor vision. Their eyes are simple (Land 1985) and they rely little, if at all, on visual cues in prey capture sequences. They can detect their prey through vibration of the substrate where the prey is concealed Movement of CLM larvae and prepupae probably creates the vibration of the leaf substrate, which could then serve as the cue for the spiders to locate the position of the larva or prepupa. The prey capture sequence for these three species of spiders followed a similar pattern. During the searching period, the spiders moved around and

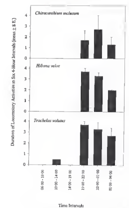

Figure 4-1 Duration of locomotory activities in three species of hunting spiders measured in six 4-hour intervals

then stopped for a while to locate the source of the vibration. Once the spider touched the prey with its legs (Figure 4-2), the spider turned very rapidly toward the prey and started to grasp the prey. Two methods of prey attack were exhibited by the three species of sac spiders. In one case, the spider punctured the mine, immobilizing the larva followed by biting and sucking the larval body fluid. In the second behavioral pattern, the spider made a slit on the mine, then pulled the larva or prepupa out of the mine using the forelegs. The first gentle touch with the forelegs was quickly changed into a powerful grip probably aided by the special hairs on the forelegs. Rovner (1978) reported that for *Cupiennius*, another genus of wandering spider, the forelegs are able to improve their secure hold by means of the adhesive hairs or scopulae on the tarsi. This could also be true for *C. inclusum*, *H. velox*, and *T. volutus*. These species possess tarsal scopulae and dense claw tufts (Roth 1993, Edwards 1958, Platnick 1974). After securing the hold, the prey was quickly pulled toward the spider's body, the chelicerae of their fangs moved apart and inserted quickly into the nearest part of the victim's body. Immediately after the bite, the tips of the legs released their grip and the prey was held in the air only with the chelicerae, thereby minimizing any danger to the spider from the prey. This is advantageous because the victim has no contact with the substrate and therefore cannot apply any directed force to free itself. Only after the prey has become immobilized by the venom does actual feeding (the chewing and the exuding of digestive juice) begin. Figures 4-3 to 4-5 show the predation sequence of these three species of hunting spiders.

The searching time or the time to locate the prey differed among the three species. *Trachelas volutus* located the prey faster than *C. inclusum* and *H. velox*. An average 5.5, 9.0, and 20 minutes were spent on prey location by *T. volutus*, *H. velox*, and *C. inclusum*, respectively (Table 4-2). Similarly, handling time or the feeding period was faster for *T. volutus* than for the other two species (Table 4-2). *Chiracanthium inclusum* and *H. velox* moved more frequently in the experimental arena than *T. volutus*.

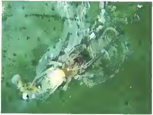

Figure 4 2 *Chiracanthium inclusum* touching or sensing the CLM larva by its handleg (arrow shows the CLM larva still within the serpentine mine)

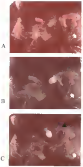

Figure 4-3 Predation sequence of *Chiracanthium inclusum* A) searching B) feeding,and C) after feeding. (arow refers to the empty mine after feeding).

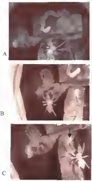

Figure 4-4 Predation sequence of *Hibana velox* A) searching, B) feeding and C) after feeding. (arrow refers to the mine after feeding).

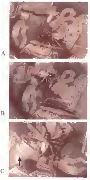

Figure 4-5 Predation sequence of *Trachelas volutus* A) searching, B) feeding and C) after feeding. (arrow refers to the empty mine after feeding)

Moreover, there was also a long period of resting for *C. inclusum* and *H. velox* after every feeding. *Trachelas volutus*, on the other hand exhibited a short resting period after every feeding. These observations could be the reason why the average percent CLM consumption was higher for *T. volutus* (90%) compared to *C. inclusum* (60%) and *H. velox* (64%) (Table 4-2)

Table 4-2 Duration of time for predation activity and the number of citrus leafminer consumed in 24 hours by the fourth-nymphal stage spiderlings of the three species of hunting spiders

Spider Species	Searching Time (min)	Handling Time (min)	% CLM consumption
Chiracanthium inclusum	22.8 ± 7.6	10.8 ± 2.5	60 ± 24.0
Hibana velox	8.8 ± 4.8	11.3 ± 5.7	64 ± 16.0
Trachelas volutus	5.5 ± 1.2	6.5 ± 4.7	90 ± 11.0

Data are means ± SE of three replications.

The developmental stages of spiders have been classified by Vachon (1957 cit. Foelix 1996) based on the postembryonic period, but there is still confusion over the description of embryonic development in spiders. The developmental stages can be summarized as follows egg - prelarva - larva - nymph (several stages) - adult. The prelarval and larval stages are not self sufficient for food and remain inside the egg sac, where they rely on the reserved yolk for food. The nymphal stages resemble miniature adult spiders. The first nymphal stage emerges from the egg sac by tearing the silken sac using their already developed chelicerae, and then they begin to locate their prey. Our observation revealed that *C. inclusum*, *H. velox*, and *T. volutus*, started to feed on CLM larvae at their first nymphal stage. This is not surprising, since spiders in general, after molting into first nymphal stage, are found to be self sufficient (Foelix 1996). At this stage, they have developed their sensory hairs, their legs are equipped with the typical claws, the eyes have the bulging lenses, and mouthparts are already differentiated for hunting and feeding. The percent CLM consumption for all the species of the hunting spiders differed among the different nymphal stages and adult stage (Table 4-3). Consumption peak was recorded at the third nymphal stage for all of the species. This stage is halfway to the adult stage, and spiders are probably more voracious at this stage in preparation to maturity. The intermolt intervals are very dependent on ample supply of food for the immature spiders to be able to develop into adult stage (Foelix 1996). *Chiracanthium inclusum* and *T. volutus* can complete their life cycle with CLM as their only food source (Table 4-3, Figures 4-6 to 4-10), however, *H. velox* was unable to complete its life cycle using CLM as the only food (Table 4-3, Figure 4-7). It could mean that this species of spider needs more varied of food to be able to complete its developmental cycle. Greenstone (1979) and Uetz et al. (1992) reported that some spiders must feed on a variety of insect prey species to obtain the optimum nutrition for survival. This may hold true for *H. velox*. For all of the species, feeding slowed down and sometimes stopped for one or two days before molting and then feeding resumed after molting (Figures 4-6 to 4-10). This phenomenon occurs naturally in all spiders. Foelix (1996) stated that most of the spiders that were preparing to molt withdraw into their retreat for several days and stop feeding.

Table 4-3 Percent CLM consumption by the different nymphal stages and adult stage of the three species of hunting spiders

Species	Nymphal stage						Adult	
	1st	2nd	3rd	4th	5th	6th	female	male
C. inclusum	38.2 ± 4.1	44.8 ± 4.1	57.0 ± 7.0	27.9 ± 7.6			37.0 ± 15.0	34.3 ± 17.0
H. velox	25.6 ± 3.0	46.2 ± 6.0	70.5 ± 6.5	57.2 ± 11.4	35.6 ± 14.0	8.4 ± 8.4		
T. volutus	58.7 ± 9.7	47.2 ± 5.4	61.3 ± 11.8	45.3 ± 14.6			70.7 ± 7.6	65.3 ± 9.6

Data are means ± S.E. of three replications.

The results obtained from this study showed the potential of the three species of hunting spiders as important mortality factors for CLM

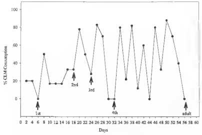

Figure 4-6 **Developmental growth of male *Chiracanthium inclusum* raised using CLM larvae (arrows refer to molt when nymphal stage begins)**

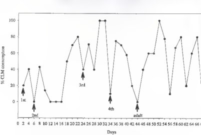

Figure 4-7 Developmental growth of female *Chiracanthium inclusum* raised using CLM larvae (arrows refer to molt when nymphal stage begins)

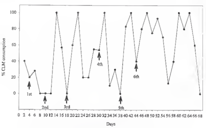

Figure 4-8 Developmental growth of *Hibana velox* raised using CLM larvae (arrows refer to molt when nymphal stage begins)

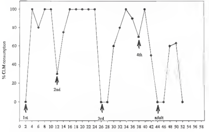

Figure 4-9 Developmental growth of male *Trachelas volutus* raised using CLM larvae (arrows refer to molt when nymphal stage begins)

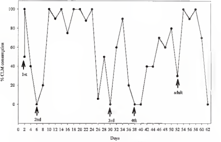

Figure 4-10 Developmental growth of female *Trachelas volutus* raised using CLM larvae (arrows refer to molt when nymphal stage begins)

CHAPTER 5
BIOLOGY OF THE THREE SAC SPIDERS ATTACKING CITRUS LEAFMINER

Introduction

Sac spiders and other related species have been reported among the dominant spiders occurring on the foliage of several plants. For instance, they are commonly reported in arthropod surveys of peanut (Agnew & Smith 1989), grape (Costello & Daane 1995), mulberry (Kurumi 1983), sunflower (Seiler et al 1987) corn (Plagens 1986), sugarcane (Breene et al 1993b), cotton (Mysore & Pritchett 1986), pine (Ali & Hartm 1988), apple (Mansour et al 1980a, Wisniewska & Prokopy 1993) and citrus (Platnick 1974, Muma 1975, Carroll 1980, Mansour et al 1982, Breene et al 1993a). According to Carroll (1980), various species of sac spiders contribute to control of lepidopterous pests as well as mites and thrips in California citrus groves. Among the sac spiders, species of the genera *Chiracanthium*, *Hibana*, and *Trachelas* are suspected to play a major role in the natural control of a number of arthropod pests. After extensive laboratory tests, Bravo-Mojica (1975 cited by Carroll 1980) found *Chiracanthium inclusum* feeding on citrus thrips. *Chiracanthium mildei*, a close relative of *C. inclusum* was common in commercial apple orchards and suspected to be an important predator of larvae and adults of the spotted tentiform leafminer, *Phyllonorycter blancardella* (F.), (Corrigan & Bennet 1987), and on larvae of *Spodoptera littoralis* (Boisd.) (Mansour 1980 a, 1980b). In addition, *Hibana (=Aysha) gracilis*, was believed to play an important role in leafhopper and leafminer control on apple (Wisniewska & Prokopy 1993). On the other hand, *Trachelas* spp. are also frequently observed on citrus foliage. Carroll (1980) reported that *T. pacificus* wanders rapidly at night over the canopy of citrus trees, groping for slow-moving or sessile prey such as thrips, mites, insect eggs and lepidopterous larvae. Regardless of the known predation potential of these group of spiders, knowledge of their biology is still fragmentary.

Peck & Whitcomb (1970) provided a detailed biological study on *Chiracanthium inclusum*; however, very little biological information has been available on any of the species of the hunting spiders or for any of the species of the families Clubionidae, Corinnidae, and Anyphaenidae and several other major families (Carroll 1980).

The aim of this study was to examine the life cycle development, rearing methods, habits and other biological aspects of the three species of sac spiders, *Chiracanthium inclusum*, *Hibana velox*, and *Trachelas volutus*, in order to better understand their role as natural enemies of arthropod pests in the lime orchards.

Materials and Methods

Rearing on different artifical and natural diets

Sources of artificial diets

The three different artificial diets evaluated for the survival of *H. velox* were soybean liquid, milk+yolk mixture, and combination diets. The soybean liquid is a non-dairy beverage (Edensoy®, Publix Supermarket, Inc., Lakeland, FL). The milk+yolk diet was a mixture of 230 ml of whole milk and one fresh chicken egg yolk blended to obtain a homogenized solution. The composition of the combination diet consisted of 230 ml of soybean beverage and 230 ml of the milk+yolk diet homogenized in a blender. The nutritional compositions of the milk+yolk soybean diets are provided in Table 5-1.

Table 5-1 Nutritional composition of milk + yolk and soybean diets based on the manufacturer's nutritional analysis per 100 ml of media.

Nutrient Composition	Milk plus Yolk[z]	Soybean[x]
Total fat	3.04 g	1.30 g
Saturated fat	1.30 g	0.0 g
Cholesterol	97.83 mg	0.0 mg
Sodium	82.61 mg	39.13 mg
Total carbohydrates	6.09 g	10.07 g
Sugars	5.22 g	6.52 g
Protein	6.04 g	2.61 g
Potassium	0.0 mg	126.09 mg
Vitamin A	348.00 IU	0.0 IU
Thiamin (B1)	0.0 mg	0.05 mg
Riboflavin (B2)	0.0 mg	0.03 mg
Niacin (B3)	0.0 mg	0.52 mg
Pantothenic Acid (B5)	0.0 mg	0.35 mg
Pyridoxine Hydrochloride (B6)	0.0 mg	0.05 mg
Folate (B9)	0.0 mg	0.02 mg
Vitamin C	0.52 mg	0.0 mg
Vitamin D	43.48 IU	0.0 IU
Biotin (Vitamin H)	0.0	0.003 g
Calcium	0.14 g	0.03 g
Iron	0.31 mg	0.31 mg
Phosphorous	0.11 g	0.04 g
Magnesium	0.0 mg	17.4 mg
Zinc	0.0 mg	0.26 mg

[z] Composition from product labels on milk and eggs. Publix Super Market Inc., Lakeland, FL 33802

[x] Composition from product label. Edensoy ® Eden Foods Inc. Clinton, Michigan 49236.)

Sources of natural diets

The natural diets included in the experiment were adults of fruit fly, *Drosophila melanogaster*, and larvae of *Phyllocnistis citrella* Stainton. The fruit flies were mass reared in the laboratory at 25–27°C and 70–80% RH. The initial population of fruit flies was obtained by exposing overripe banana fruits enclosed in a glass jar. The fruit fly adults trapped were brought back to the laboratory for mass rearing. The artificial diet used for rearing the fruit flies was the banana medium described by Yoon (1985) with some modifications (see Appendix C for the detailed diet preparation). Approximately 10 ml of the medium was dispensed under a fume hood into a sterilized glass vial (15 mm diameter x 60 mm long) using a sterilized beaker. When the medium was cool, a sterilized strip (1cm x 5cm) of filter paper was inserted in each vial. The mouth of the vial was then plugged with sterilized cotton balls. The vials were stored for a day at 20°C before use or stored at 4°C until needed.

Fruit flies

Adult fruit flies from the initial stock were immobilized by placing them in a freezer (~0°C) for 30 to 40 seconds. Immobilized fruit flies were transferred in an empty glass jar and etherized for a longer period of immobilization. Then, five males and five females were transferred in each culture vial. The culture vials were kept in an incubator conditioned at 27 °C and 80% RH. Adults from the succeeding cultures were mass reared. To avoid inbreeding, adult fruit flies from different stock cultures were mixed for re-culturing.

A one-week-old fruit fly culture was utilized for spider rearing. This provided three to four weeks of continous supply for the spider in the rearing cage.

Citrus leafminer

Citrus leafminer larvae were usually collected from an unsprayed orchard or from the greenhouse and kept in 35cm x 30cm x 30cm plastic cages until adult emergence.

Sac spiders

Egg sacs of *Chiracanthium inclusum*, *Hibana velox*, and *Trachelas volutus* were collected in the field and brought back to the laboratory and put inside an incubator kept at 27°C and 80% RH until spiderling emergence. First instar spiderlings were used in the experiment.

Effect of artifical diets on the survival of *Hibana velox*

This experiment is a follow-up of the preliminary test conducted to compare the efficiency of some artificial diets for spider rearing (Appendix B) The different artificial diets (soybean liquid, milk+yolk mixture, and a combination diet) included in this experiment were modified based on the results gathered from the previous preliminary test. The detailed compositions of each of these diets were listed in Table 5-1

Hibana velox was used in a preliminary test to evaluate the artificial diets. A single first instar spiderling was placed in a laboratory glass vial (15 mm diameter x 60 mm long) (Figure 5-1) with one-tipped stemmed cotton swab saturated with the artifical diet and sealed with cotton. The cotton swab was replaced every two days. The experiment was replicated three times with 20 spiderlings included in each replication for each artificial diet treatment Water served as the control All the vials were kept in an incubator set at 27 °C, 80% RH and a LD 12 12 photoperiod Spider mortality was recorded every two days for 10 weeks Molting periods were recorded by checking the presence of exuviae in each vial. The rate of developmental growth in the different artifical diets was compared using one way analysis of variance (ANOVA)

Comparison between artifical and natural diets on survival of *C. inclusum*, *H. velox*, and *T. volutus*

Three different containers were used for artifical and natural rearing (Figures 5-1, 5-2, and 5-3)

1) The spiders reared in the artifical diet were placed in laboratory glass vials (15 mm diameter x 60 mm long) (Figure 5-1) following the same methodology as explained in the preliminary tests The diet used was the combination diet with a slight modification

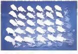

Figure 5-1 Rearing set-up for the combination diet.

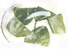

Figure 5-2 Rearing set up for the spiders using larvae of CLM.

Figure 5-3 Rearing set-up for the spiders using adults of *Drosophila*

(230 ml of soybean beverage, 230 ml of homogenized whole milk, 2 fresh chicken egg yolks, and 5ml honey).

2) To rear the species using *D. melanogaster* as a substrate, newly emerged spiderlings were individually placed in a translucent plastic container (70 cm high x 70 cm long x 20 cm wide) (Figure 5-2) with two circular openings (2 cm diameter) at the two opposite sides. A 30-ml vial with 10 ml of water and plugged with cotton was inserted through the first opening, while a glass vial containing a one-week old culture of *D. melanogaster* adults in banana medium was inserted through the second circular opening.

3) The spiders reared on ten second-instar larvae of *P. citrella* were placed inside a plastic petri dish (10 cm in diameter x 1 cm high) lined with moistened filter paper (Figure 5-3). The second instar larvae of CLM were collected in the field or in the greenhouse culture depending on the availabilty of the larvae on both places.

Thirty spiders of each species were reared from egg to maturity in the different diets. All spiders were put in an incubator kept at 27°C and 80% RH. The artificial diet and CLM larvae were replaced every 2 days whereas *D. melanogaster* cultures were checked every two weeks and replaced as needed. The survival and the developmental rate of the three sac spiders reared in artificial and natural diets were compared using DMRT.

Biology of the sac spiders

The life cycles of *C. inclusum*, *H. velox*, and *T. volutus* were studied. In this experiment, *C. inclusum* and *T. volutus* were reared using second instar larvae of CLM, whereas *H. velox* were reared using the modified combination diet. For all the species, rearing was done following the methodology explained in the evaluation of artificial and natural diets on the survival of spiders. Thirty individuals for each spider species were included in the experiment.

Daily observations were recorded in order to obtain a complete picture of molting and other biological factors. Some adult male and female spiders were kept in a single container to observe mating, courtship, oviposition, and maternal care

Results and Discussions

Rearing on Different Artificial Diets

Effect of artificial diets on the survival of *H. velox*

The percent survival of *H velox* differed significantly between the control (only water) and the three artificial diets (Figure 5-4) Over a ten-week rearing period, the percent survival of the spiders raised on combination diet was higher than on soybean liquid but not significantly different, however, both diets had significantly higher percent spider survival than on milk+yolk diet The control treatment using water alone as diet had the lowest percent spider survival. Table 5-2 shows the percent spider survival in each week for a period of ten weeks. During the 1st and 2nd week, percent spider survival was not significantly different among the different artificial diets. From week 3 to week 10 the percent spider survival was significantly higher in soybean liquid and combination diets compared to the milk+yolk mixture diet except in the 7th week in which percent spider survival in soybean liquid and milk+yolk diets did not significantly differ from each other All the spiders in the control diet died three weeks after treatment

Developmental growth of *H velox* on different artificial diets

The developmental growth of *H velox* in the different artificial diets was recorded based on percent and time of molting (Figures 5-5 to 5-7) The growth of spiders differed in the different artificial diets Only two percent of the spiders raised on soybean liquid

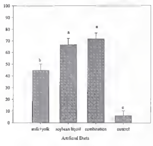

Figure 5-4 Percent survival of *H. velox* reared on different artificial diets. Bars with the same letters are not significantly different according to DMRT ($P \leq 0.05$)

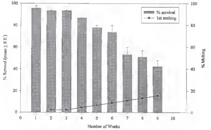

Figure 5-5 Percent spider survival and percent molting of *H. velox* reared on soybean liquid diet.

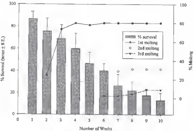

Figure 5-6 Percent spider survival and percent molting of *H. velox* reared on milk+yolk diet.

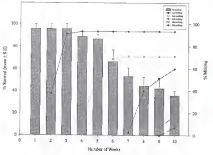

Figure 5-7 Percent spider survival and percent molting of *H. velox* reared on combination diet

Table 5-2 Percent survival of *Hibana velox* in 10 weeks on three different artificial diets and the control raised under laboratory conditions at 27°C and 80%RH.

Week	Artificial Diets			
	Milk+yolk	Soybean	Combination	Control
1	86.67 a	95.53 a	95.57 a	60.00 b
2	86.63 a	95.53 a	95.57 a	60.00 b
3	68.87 b	93.30 a	95.57 a	0.0 c
4	60.00 b	86.70 a	88.87 a	0.0 a
5	46.67 b	77.77 a	86.67 a	0.0 c
6	39.97 b	73.33 a	66.67 a	0.0 c
7	26.67 bc	53.33 ab	57.77 a	0.0 c
8	22.33 b	51.10 a	51.10 a	0.0 b
9	17.80 b	42.20 a	42.23 a	0.0 b
10	17.80 b	42.20 a	42.23 a	0.0 b

Means followed by the same letters in the same row are not significantly different (P≤0.05) according to DMRT

diet underwent one single molting during week 2 of rearing (Figure 5-5). The peak of molting was observed during week 9, but by week 10, all of the spiders raised on this diet died. More molting stages occurred on spiders raised on milk+yolk mixture and combination diets (Figures 5-6 & 5-7). Spiders raised on milk+yolk diet molted 3 times (Figure 5-6). A mean of 24.4 % of the total spiders molted in week 2 and the percent molting increased as the rearing continued. The peak of the percent molting for the first molt was in week 6 in which 80% of the surviving spiders molted. Almost 50% of the surviving spiders underwent a 2nd molting from week 4 to week 10 (Figure 5-6). Spiders raised on the combination diet exhibited the highest number of molting stages (n=5) (Figure 5-7). The first molting started on week 2 with a mean percent molting of almost 40% and reached 93.3% by week 4. The second molting started during week 3 which was a week earlier than on milk+yolk mixture diet, however, percent molting started to increase in week 4 and the peak of molting was recorded in week 7. The peak of the third molting was recorded during week 10, however, very few spiders reared on milk+yolk mixture diet underwent 4th and 5th molting.

Results from this experiment confirmed our hypothesis (Appendix C) that a combination diet provides a better dietary requirement for the juvenile stages of spiders. The information gathered from this study is relevant in formulating an artifical diet for *Hibana velox* and other related species. Each component of the combination diet has an important nutrient for the growth and survival of spiders under laboratory conditions. For instance, the soybean liquid diet has a high level of carbohydrates as the major energy source for survival or longevity (Singh 1984). It was also observed that the presence of soybean in the diet contributed to increased survival of the spiders (Figures 5-5 & 5-7). The egg yolk has a high level of cholesterol which is a precursor of ecdysone or the molting hormone (Foelix 1982) that appears to accelerate the developmental growth of the spiders by having more molting stages and higher percent survival (Figures 5-6 & 5-7). This may suggest that the combination diet provided a more complete dietary requirement for *H. velox* than the other tested diets.

Comparison Between Artificial Diet and Natural Diet

The developmental growth and percent survival of the three sac spiders raised on artifical and natural diets are shown in Figures 5-8 to 5-10. In the combination diet, the three sac spiders were able to develop into the adult stage (Figure 5-8). After the 6th and 7th moltings most of the spiders developed to maturity. In general, percent survival of *H. velox* was relatively higher than *C. inclusum* and *T. volutus* in all the growth stages. Some related species of sac spiders are reported to be nectar feeders (Taylor and Foster 1996). It is possible that the three species of sac spiders included in this experiment are also nectar feeders as they were able to survive and develop partially (*H. velox*) or completely (*C. inclusum* and *T. volutus*) on combination diet.

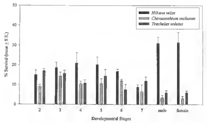

Figure 5-8 Developmental growth of *C. inclusum*, *H. velox*, and *T. volutus* reared on artificial combination diet

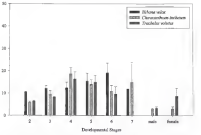

Figure 5-9 Developmental growth of *C. inclusum*, *H. velox*, and *T. volutus* reared on larvae of CLM.

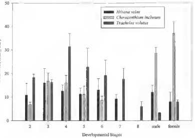

Figure 5-10 Developmental growth of *C. inclusum*, *H. velox*, and *T. volutus* reared on adults of *Drosophila*

Moreover, Vogelei & Greissl (1989) showed that newly emerged *Thomisus onustus* Walckenaer (Araneae: Thomisidae) spiderlings, deprived of prey but with continuous access to 30% sucrose solution, lived for about four months.

Spiders reared using larvae of CLM alone were able to develop to the adult stage except for *Hibana velox* (Figure 5-9). This finding suggests that *H. velox* needs different food sources to be able to complete its development. Moreover, prey consumption by the immature *H. velox* was relatively higher than *C. inclusum* and *T. volutus*. This observation suggests the potential of these three sac spiders as biological control agents of CLM, which is one of the major pest of citrus species. Evaluation of their efficiency as biological control agents of CLM is presented in Chapter 3. The three sac spiders reared on *Drosophila* were able to develop to the adult stage (Figure 5-10).

This experiment demonstrated the need to improve artificial diets for a better spider rearing strategy under laboratory conditions. Moreover, this may open the possibility of mass rearing the most important species of spiders in agriculture for possible augmentation in the field. It strongly suggests that different proportions of the ingredients in combination diets must be evaluated for better survival and reproduction. It is also worthwhile to investigate further the efficiency of combining the use of artificial and natural diets in spider rearing.

Biology of the Three Sac Spiders

Eggs and postembryo

The egg masses of the three species of sac spiders included in this experiment vary in size and shape. The egg mass of *C. inclusum* is generally an oblate spheroid (Figure 5-11). Individual eggs are spherical, non-agglutinate and their size (5.0 ± 1.0mm) depends on the number of eggs produced. The eggs are pale yellow, with a translucent, frosty

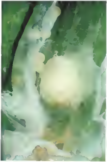

Figure 5.11 Egg mass of *Chiracanthium inclusum*

appearance and are clearly visible through the silken covering sheath. The thin, finely spun egg sac in which they are contained is suspended within a much more tightly woven brood cell in which the female encloses herself with the egg mass.

In *H. velox*, the egg mass is flat oblong (Figure 5-12) with an average size of 8.0± 1.2 mm. The eggs are creamy in color and spherical. The egg mass is laid inside the retreat or egg nest, where the female encloses herself. The egg mass of *T. volutus* is contained inside a circular papery cocoon fastened on a flattened surface (Figure 5-13). In the field, the egg cocoon is usually located on the surface of leaves, branches, trunks, and fruits. The female stays on top of the cocoon to guard the egg mass. The egg mass has an average size of 4.5± 0.9 mm. The egg is round and pale yellow in color.

Egg eclosion starts when the contours of the embryo, especially those of the appendages, become imprinted upon the chorion. This took 10± 2.1 days for *C. inclusum* (Figure 5-14), 12±1.2 days for *H. velox* (Figure 5-15), and 15±2.3 days for *T. volutus* (Figure 5-16). For all the species, the first postembryo emerged after 24 hours. The first postembryo is immobile, its appendages appressed to the body and still surrounded by the very thin, transparent vitelline membrane. Within two days after the chorion is cast, the membrane recedes all of the appendages of the embryo and by the time the vitelline membrane has been shed completely, the second postembryo begins to struggle effectively. Within half an hour after emergence, the second postembryo walks around the brood cell. The second postembryo, hardly mobile at first, almost invariably climbs to the inside of the top of the brood cell where it clings and moves slowly for the seven days that it remains in this stage of development. The newly emerged, active second postembryo of *C. inclusum* and *H. velox* are pale yellow and devoid of markings and other pigmentation whereas the second postembryo of *T. volutus* is light gray and also devoid of any body ornamentation. In six days, the appendages acquire a dark pigmentation caused by the hairs and spines developing on the forming

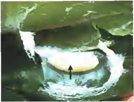

Figure 5-12 Egg mass of *Hibana velox*

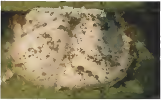

Figure 5.13 Egg mass of *Trochelus volutus*

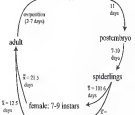

Figure 5-14 Complete developmental cycle *Chiracanthium inclusum* reared under laboratory conditions.

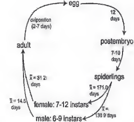

Figure 5-15 Complete developmental cycle of *Hibana velox* reared under laboratory conditions.

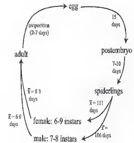

Figure 5-16 Complete developmental cycle of *Trachelas volutus* reared under laboratory conditions.

cuticle. For all species, the postembryonic stage lasted from 7 to 10 days (Figures 5-14 to 5-16). The first molt occurs about 24 hours after the pigmentation is evident. This is the 1st instar spiderling.

Ecdysis

About two days before molting the spiderlings of the three sac spider species become less active and reject food even though they are capable of normal movement and will attack and kill any prey that disturbs them. At this period the spider is normally enclosed in a resting cell cocoon. A successful molt takes place at about 15 to 20 minutes. If something goes amiss during the process, the spider may struggle for 1 hour or more, and sometimes the struggle ends with death.

Number of molts and duration of development

Chiracanthium inclusum was found to mature after the 7th molt for both males and females (Figure 5-14). For *H. velox* female and males mature after the 7th molt and after the 6th molt, respectively (Figure 5-15). In *T. volutus*, the female matures at any instar after the 6th molt and the male matures after the 7th molt (Figure 5-16). The number of immature instars varied with sex and among individuals within the same sex (Figures 5-14 to 5-16). Male *C. inclusum* underwent 7–8 instars for a mean period of 98.1 days whereas the females underwent 7-9 instars for a mean period of 101.6 days. It takes an aveage of 21.5 days for females and 12.5 days for males to develop to full maturity after molting to last immature instar. For *H. velox*, the female underwent 7–12 instars for an average period of 171.0 days and and the male underwent 6-9 instars for an average period of 130.9 days. It takes an average of 31.2 days and 14.5 days for a female and male, respectively, to reach full maturity after the last immature instar molting. In *T. volutus*, the female underwent 6–9 instars for an average period of 111.0 days, and the male underwent 7–8 instars for an average period of 106.0 days. The female reaches full maturity at an average of 8.3 days and an average of 6.0 days for the male after the last immature instar molting. The spiderling reaches the point of its 1st true molt 17 to 20 days after oviposition for *C. inclusum*, 19 to 22 days for *H. velox*, and 22–25 days for *T. volutus*. All subsequent instars had a wide duration, even for individuals of the same parentage and reared under the same conditions. Table 5-3 shows the life histories of the three sac spider species. Under standard laboratory conditions, adult females of *C. inclusum* lived an average of 95 days; adult males, on the other hand, lived an average of 58 days. The total life span was an average of 214.6 days and 177.1 days for females and males, respectively. Adult females of *H. velox* lived for an average of 121 days and for an average of 90 days for males. The total life span averaged 311 days for females and 239.9 days for males. On the other hand, *T. volutus* females lived for an average of 120 days and the males lived an average of 82 days. The total life span was an average of 253 days and 212.3 days for females and males, respectively.

Table 5-3 Life histories of *C. inclusum*, *H. velox*, and *T. volutus* reared from egg to maturity under controlled laboratory conditions (27°C, 80% RH)

Species	Females				Males			
	Days to Maturity (mean	# of stadia ± S.E.)	adult life span	total life span	Days to Maturity (mean	# of stadia ± S.E.)	adult life span	total life span
C. inclusum	119.6 ± 18.3	7.5 ± 0.5	95	214.6	119.1 ± 16.2	7.6 ± 0.8	58	177.1
H. velox	190.2 ± 35.2	8.7 ± 0.8	121	311	149.9± 27.8	7.2 ± 0.5	90	239.9
T. volutus	133.0 ± 21.0	7.3 ± 0.6	120	253	128 ± 21.2	6.7 ± 0.2	82	212.3

Our findings and observations on the behavior of *C. inclusum* are similar to those of Peck and Whitcomb (1970) regarding the distinctly different construction of the brood cell and the egg sac. The female and male pair spend much of their time in the brood cell

In nature, both kinds of cells are constructed in protected places such as curled leaves, or formed between the fruit and its peduncle. In the laboratory, they are constructed in almost any corner of the spider's container. The resting cell is cylindrical, 5 mm in diameter and 20–25 mm in length. The cell may be open on a side or on the 2 sides or completely enclosed and woven more delicately. The egg sac is larger and more spherical than the resting cell, it is woven more tightly and densely and is always sealed off completely from the outside environment. A female remains in close contact with the eggs for the entire period, moving around them periodically and touching them with her palpi. Later on, the female continues to care for the 1st instar spiderlings. The behavior of the other two species, *H. velox* and *T. volutus* was similar to that of *C. inclusum* in terms of maternal care. Moreover, the spiderlings of these three sac spider species depend on their mothers, who tear the fabric of the brood cell so that the spiderlings can emerge from the egg sac.

Females that matured and were fertilized in captivity produced 1–3 egg masses. The oviposition took place 2–7 days after mating for all of the species (Figures 5-14 to 5-16). The number of egg masses was directly proportional to the life span of the female. The number of eggs per egg mass of *C. inclusum* reared in the laboratory varied from 36 to 86 with an average of 57 eggs. Edwards (1958) reported 112 eggs in a single egg mass and Peck & Whitcomb (1970) reported a range of 17–86 eggs per egg mass. The number of eggs laid by female *H. velox* ranges from 96 to 120 with an average of 110 eggs. *Trachelas volutus* produced 47 to 66 per egg mass with an average of 56 eggs.

Feeding behavior

For all the species, the first true molt spiderlings or the second instar spiderlings actively fed on CLM larvae. This suggests a potentially high number of spiders that can attack CLM in the field.

CHAPTER 6

SELECTIVE TOXICITY OF SOME PESTICIDES TO *HIBANA VELOX*, A PREDATOR OF CITRUS LEAFMINER

Introduction

Various species of spiders are found commonly inhabiting lime orchards in south Florida. A preliminary survey revealed that three species of hunting spiders, namely Chiracanthium *inclusum* Hentz, *Hibana velox* (Becker), and *Trachelas volutus* (Gertsch) and one species of jumping spider, *Hentzia palmarum* (Hentz), feed on the larvae and prepupae of [Chapter 3 and Chapter 4] In addition to the vast range of insecticides used for CLM control (Beattie et al 1995, Heppner 1993), citrus trees, particularly in nurseries, are regularly treated with pesticides to protect them from other arthropod pests and diseases (Villanueva-Jimenez & Hoy 1997, Knapp 1996) This threatens the survival and sustainability of the native and introduced natural enemies (Browning 1994, Peña & Duncan 1993, Villanueva-Jimenez 1998)

The use of selective pesticides is a major consideration for developing an integrated control program. Employing pesticides that are relatively harmless to spiders and other predatory arthropods could increase the effectiveness of natural predation and thereby, reduce the population of injurious insects in lime orchards

In this study, we tested under laboratory conditions the susceptibility of the hunting spider, *Hibana velox* (Araneae Anyphaenidae), to some commonly used pesticides in lime orchards.

Materials and Methods

Toxicity tests of 14 pesticides recommended for citrus (Knapp, 1996) were conducted in the laboratory on spiderlings of *H. velox*. Table 6-1 shows the target insect pests and diseases of the selected 14 pesticides. Test organisms were obtained by collecting egg sacs of *H. velox* in the field. The egg sacs were transported to the laboratory for spiderling emergence. Two-week-old spiderlings were utilized in the tests since at this developmental stage they start to feed on CLM larvae. Two methods were developed for the bioassay: surface coating and dipping. The selective efficiency of these two methods in assessing pesticide effect on hunting spiders was compared.

Table 6-1 Pesticides tested for the laboratory bioassay and the pests where they are recommended to control (Knapp, 1996)

Trade Names	Common Names	Arthropod Pests	Diseases
Agrimek	Avermectin	citrus rust mites, broad mites, citrus leafminer	
Agrimek + Oil	Avermectin + Oil	citrus rust mites, broad mites, citrus leafminer	
Oil	FC - 41266	citrus rust mites, broad mites, citrus leafminer, scale, whitefly, spider mites	greasy spot, sooty mold
Admire, Provado	Imidacloprid	citrus leafminer	
Copper	Tri Basic		phytophthora, foot rot, root rot, brown rot, greasy spot, melanose, citrus scab, alternaria brown spot
Dimilin	Diflubenzuron	citrus rust mites, root weevil, citrus leafminer	
Dipel	*Bacillus thuringiensis*	orange dog,	
Ethion	Ethion	citrus rust mites, citrus snow scale	
Guthion	Azinphos methyl	scales, whitefly, mealybug, adult citrus root weevil, cricket	
Kelthane	Dicofol	spider mites, citrus rust mites	
Lorsban	Chlorpyrifos	scale, mealybugs, orange dog, katydid, grasshopper, termites, fireants, aphids, crickets	
Neemix	Azadirachtin	citrus leafminer	
Sevin	Carbaryl	citrus root weevil, orange dog, katydids, grasshoppers, crickets	

Surface Coating Method

Surface coating (Figure 6-1) was done by exposing the spiders to surface coated glass vials (15mm diameter x 60 mm long) with pesticide solution. Each vial was coated with pesticides by dispensing 80µl of the pesticide solution. The vials were rolled manually until the whole surface was coated with the solution and kept for an hour or until they were completely dry. The spiders were placed individually in the surface coated vials. Each spider was provided with the artificial combination diet following the procedure in evaluating the different artifical diet on the survival of *H. velox* described in chapter 5.

Three concentrations of each pesticides were tested, i.e. simulated field rate (SFR), twice SFR, and half SFR. The different concentrations were prepared using deionized water for all the pesticides except for the technical grade of avermectin and imidacloprid-Admire in which acetone was used as a solvent. A bioassay using the surface coating method was conducted for nine pesticides i.e. avermectin, azinphos-methyl, carbaryl, chlorpyrifos, dicofol, ethion, imidacloprid-Admire, imidacloprid-Provado, and copper fungicide.

Dipping Method

Dipping was done by cutting lime leaves into 25 mm diameter circles. The leaf circles were dipped separately for approximately 30 seconds in different concentrations of five pesticides, i.e., azadirachtin, *Bacillus thuringiensis*, diflubenzuron, avermectin + petroleum oil, and oil alone. After dipping, the leaves were air-dried for approximately 2 h or until dry and placed singly on the bottom of a 30-hole (25 x 30 mm) cup tray (Figure 6-2). A single spiderling was added to each arena and fed with the artificial combination diet provided in a cotton swab. The cup holes were covered with a plastic lid. For both

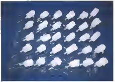

Figure 6-1 Surface coating method

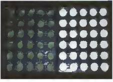

Figure 6-2 Dipping method

ten individual spiders were tested for each concentration. The control was deionized water for all pesticides except for avermectin and imidacloprid-Admire in which acetone was used as control. The arenas were placed in the incubator conditioned at 27 °C and 80% RH. The tests were done in three replications. The spiders were held in the treated substrates for 72 h and their survival was compared with the control from day 1 to day 3 after treatment. LD_{50} values were estimated by Probit Analysis using POLO program (Russell et al. 1977). When mortality was low at all concentrations tested, the LD_{50} value was not estimated, the percent mortality was compared among the different concentrations.

Results and Discussion

A wide range of toxicity was exhibited by the different pesticides included in the bioassay tests. Among the nine pesticides tested using the surface coating method, imidacloprid-Admire, a chlorinated derivative of nicotine drench formulation and tri basic, a fungicide, showed low percent spider mortality (10-30%), producing the lowest mortality even at the highest concentration (twice of SFR) (Figure 6-3). This suggests that both pesticides have low or no acute impact on *H. velox*. Avermectin, a soil actinomycete-produced compound and imidacloprid Provado, a chlorinated derivative of nicotine spray formulation had moderate toxicity on *H. velox*. Both showed more than 50% mortality at the highest concentration and about 35% using SFR (Figure 6-3). The estimated LD_{50} values were 14.68 and 0.21, respectively (Table 6-2). The organophosphates (azinphos-methyl, chlorpyrifos, and ethion), the carbamate, carbaryl, and the organochlorine, dicofol, were all highly toxic causing 100% spider mortality even at the lowest concentration (half of SFR) (Figure 6-4). The estimated LD_{50} value was 0.002 for all of these broad-spectrum insecticides (Table 6-2). In the dipping method, oil alone exhibited a low

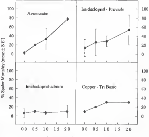

Figure 6-3. Percent mortality of spiders exposed to three different concentrations of Avermectin, Imidacloprid-Provado, Imidacloprid-Admire, and Copper-Tri Basic.

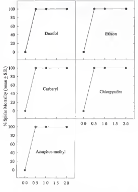

Figure 6-4 Percent mortality of spiders exposed to three different concentrations of five broad-spectrum insecticides

Table 6-2. LD50 values of pesticides showing moderate to high toxicity on *H. velox*

Pesticides	Simulated Field Rate (SFR)	LD50 (90% FL)[a]
avermectin	10 (g/ml)	14.68 (8.79-30.2)
azinphos-methyl	2.5 (l/ml)	0.002 (0.0-0.0)
carbaryl	2.5 (l/ml)	0.002 (0.0-0.0)
chlorpyrifos	2.5 (l/ml)	0.002 (0.0-0.0)
dicofol	3.0 (l/ml)	0.002 (0.0-0.0)
ethion	3.0 (l/ml)	0.002 (0.0-0.0)
imidacloprid Provado	0.27 (l/ml)	0.21 (0.01-0.33)

[a] LD50's are based on the simulated field rate and expressed as g/ml or l/ml as indicated in the table

toxicity on *H. velox*. Only 15% mortality was recorded from the highest concentration, 5% from the simulated field rate, and 0% from the lowest concentration (Figure 6-4), however, oil + avermectin, caused moderate toxicity. This clearly shows that avermectin has a moderate effect and this has been indicated using avermectin alone (Figure 6-3). The naturally derived products i.e. azadirachtin (neem extracts), *Bacillus thuringiensis* (insecticidal bacterium), and diflubenzuron (insect growth regulators) showed high selectivity to *H. velox*. Less than 30% mortality was recorded at the highest concentration for all of these products (Figure 6-5).

Other laboratory studies showed that the broad-spectrum insecticides such as organophosphates, carbamates and organochlorines have significant lethal effects on spiders in general. For instance, in Israel, laboratory residue studies using grapefruit leaves as the substrate showed that organophosphate (chlorpyrifos) was highly toxic to *Chiracanthium mildei* a hunting spider known to occur abundantly in citrus orchards whereas the natural insecticides, i.e. *Bacillus thuringiensis* and neem extracts, were virtually non-toxic to spiders. Saxena et al. (1984) found that topical application of 50μg of a neem seed kernel extract did not affect the spider, *Lycosa pseudoannulata*, a major predator of brown planthopper in Southeast Asia.

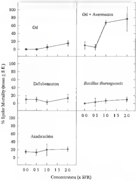

Figure 6-5 Percent mortality of spiders exposed to three different concentrations of naturally derived pesticides

On the other hand, fungicides have been shown to have little or no toxicity for spiders (Stark et al 1995) Thus, our result on the toxicity tests of these different groups of pesticides on *H velox* are comparable to findings of previous laboratory bioassays conducted on other species of spiders

Some of the pesticides tested in this study were also included in the toxicity tests on adults of *Ageniaspis citricola* an introduced parasitoid against CLM (Villanueva-Jimenez 1998) The naturally derived products i e neem, azadirachtin, and the insect growth regulator, micromite, which we found having no impact on *H velox* was also found selective for *A citricola*

The impact of imidacloprid on *H velox* and *A citricola* also showed a similar trend Imidacloprid-provado applied to foliage was non-selective, while imidacloprid-admire used as drench was selective to both *A citrricola* and *H velox* Ethion, a broad-spectrum organophosphate, was non-selective for both *H velox* and *A citricola* Avermectin was moderately selective for *A citricola* and *H velox* Petroleum oil was the safest pesticide for spiders It was also most selective for *A citricola* (Villanueva-Jimenez 1998) Petroleum oil, which is traditionally used as suffocant, seems to be ideal as a component for a pest management program for CLM on limes Petroleum oil has a short residual activity on natural enemies (Beattie & Smith 1993, Erkilic & Uygun 1997, Beattie et al 1995), and is cost-effective (Beattie 1992, Beattie et al 1995)

The similarity of these results with other studies on other predatory species and parasitoids and those obtained from these tests indicate that the impact of pesticides on the existing pest/natural enemy complex must be taken into consideration

CHAPTER 7
DISSERTATION SYNOPSIS

Summary of Results

Survey of Spiders Occurring in Lime Orchards

A preliminary survey of predatory arthropods in lime orchards at Homestead, Florida showed that spiders significantly outnumbered the other predatory arthropods, i.e. green lacewing (*Chrysoperla rufilabris*), coccinellid (*Harmonia* sp.), and ant (*Myrmelachista* sp.). The spider community consisted of 9 families, 24 genera, and 16 identifiable species, which were further grouped into three guilds: web-builders, hunters, and ambushers. Three families represented the web-builders (i.e. Araneidae, Tetragnathidae and Theridiidae), five families represented the hunters (i.e. Anyphaenidae, Clubionidae, Corinnidae, Lycosidae, and Salticidae) and one family represented the ambushers (i.e. Thomisidae). Among the web builders, *Theridion* sp. was the most abundant in all orchards, whereas, among the hunters four species occurred abundantly: three species of sac spiders (i.e. *Chiracanthium inclusum*, *Hibana velox* and *Trachelas volutus*) and one species of jumping spider (i.e. *Hentzia palmarum*).

Comparison of three sampling methods revealed that the visual sampling method provided the highest number of spiders collected followed by the shake-cloth method and the DVAC suction method collected the least. The sampling method had a significant effect on mean density of every spider species grouped into two major guilds. There were more hunting spiders collected using the visual and shake-cloth methods than using the DVAC, whereas more web building spiders were collected using the DVAC except for the *Theridion* sp., which was more frequently found using the visual and shake-cloth methods.

Survey of predatory arthropods in sprayed and nonsprayed lime orchards showed that the number of predatory arthropods was significantly higher in the nonsprayed orchards than in the sprayed ones Among the spiders, numbers of hunting spiders were significantly higher on nonsprayed than on sprayed orchards for web building spiders, there was no significant difference in the spider abundance between the sprayed and nonsprayed orchards.

Predation by the Three Species of Sac Spiders

Feeding tests on 14 commonly encountered spider species in lime orchards confirmed that four species of hunting spiders (3 species of sac spiders, *C. inclusum*, *H velox* and *T volutus* and a jumping spider *Hentzia palmarum*) fed on CLM larvae and in some cases prepupae. To further test the predation potential of these spiders, feeding efficiency tests on the three sac spider species were conducted in the laboratory, greenhouse, and field conditions Results of the laboratory feeding efficiency tests showed that the predation rate of the three species of sac spiders can be ranked as follows. *H velox* > *C. inclusum* > *T volutus* The trend or ranking of predation rate under greenhouse conditions is similar to the result obtained from the laboratory efficiency test Since *H velox* was found to be a more efficient predator compared to *C inclusum* and *T volutus* under the laboratory and greenhouse conditions, its predation potential was further tested under field conditions. The results of the field cage experiments indicated that as the density of the prey increases, the number of prey consumed by *H velox* also increases suggesting a sigmoid functional response curve In addition, significantly more CLM larvae were consumed when two to three spiders were placed in each cage

Gut content analysis using polyacrylamide gel electrophoresis (PAGE) was done on the three sac spider species. Results from the electrophoresis showed that *H velox* that fed on the artificial medium gave one esterase band, which is different from the CLM esterase, whereas, no esterase was obtained from the *C. inclusum* and *T. volutus* fed with artificial medium. The esterase obtained on *C. inclusum* and *H. velox* fed with CLM larvae in the laboratory seems to be similar to the CLM esterase. No esterase activity was obtained from *T. volutus* that fed on CLM larvae.

Predatory Behavior of the Three Species of Sac Spiders

Observation of spider activities during photophase and scotophase confirmed that *C. inclusum*, *H. velox*, and *T. volutus* are all nocturnal. They can detect their prey through vibration of the substrate where the prey is concealed. Movement of the CLM larvae and prepupae probably creates the vibration of the leaf substrate, which could then serve as the cue for the spiders to locate the position of the larvae and prepupae. The prey capture sequence for these three species of spiders followed a similar pattern. During the searching period, the spiders moved around and then stopped for a while to locate the source of the vibration. Once the spider touched the prey with its legs, the spider turned rapidly toward the prey and started to grasp the prey. Two methods of prey attack were exhibited by the three species of sac spiders. In one case, the spider punctured the mine, immobilizing the larva followed by biting and sucking the larval body fluid. In the second behavioral pattern, the spider made a slit on the mine, then pulled the larva or prepupa out of the mine using the forelegs, then held the prey securely followed by biting and sucking of the larval body fluid.

The three species of sac spiders started to feed on CLM larvae during their first nymphal stage. Consumption increased as they developed to later nymphal stages. Consumption peak was recorded at the third nymphal stage for all the species. This stage is halfway to the adult stage, and spiders are probably more voracious at this stage in preparation to maturity. *Chiracanthium inclusum* and *T. volutus* can complete their life cycle with CLM as the only food, whereas, *H. velox* was not able to develop to the adult stage. It could mean that that species of spiders needs more varied food to be able to complete its developmental cycle.

Biology of the Three Sac Spiders

Rearing of spiders under laboratory conditions using different diets was done to study the detailed biology of the three species of sac spiders The effect of artificial diets, i e milk+yolk, soybean liquid and combination diets was evaluated on the survival and development of *H velox* Results showed that over a 10-week rearing period, the percent survival of the spiders raised on soybean liquid diet and combination diets were not significantly different, however, spider survival on milk+yolk diet was significantly lower compared to the other two artificial diets The growth of the spiders differed in the different artificial diets. More molting stages occurred on spiders raised on milk+yolk and combination diets compared to soybean liquid diet Spiders raised on the combination diet exhibited the highest number of molting stages suggesting that combination diet provide a better dietary requirement especially for the juvenile stages of the spiders

The developmental growth and percent survival of the three sac spiders on artificial diet (i.e combination diet) and natural diets (i.e. CLM larvae and *Drosophila* adults) were compared. In the combination diet, the three sac spiders were able to develop into the adult stage Similarly, the three sac spiders reared on *Drosophila* adults were able to develop to the adult stage, whereas, only *C. inclusum* and *T. volutus* reared in CLM larvae were able to develop to the adult stage. *Hibana velox* died after the 7th molt

The biology of the three species of sac spiders was studied on spiders reared on CLM larvae (*C. inclusum* and *T volutus*) and on combination diet (*H velox*) under controlled laboratory conditions *Chiracanthium inclusum* was found to mature after the 6th molt for both males and females Male underwent 7-8 instars for a mean period 98 1 days and the females underwent 7-9 instars for a mean period of 101.6 days. The total life span was an average of 214.6 days and 177.1 days for females and males, respectively. *Hibana velox* females and males matured after the 7th molt and after the 6th molt, respectively. Females underwent 7-12 instars for an average period of 171 days and the males underwent 6-9 instars for an average period of 130.9 days. The total life span averaged 311 days for females and 239.9 days for males. *Trachelas volutus* females matured after the 6th molt and the males after the 7th molt. Female underwent 6-9 instars for an average period of 111.0 days and the male underwent 7-8 instars for an average period of 106.0 days. The total life span was an average of 253 days for females and 212.3 days for males. For all the species, females that matured and were fertilized in captivity produced 1-3 egg masses. The oviposition took place 2-7 days after mating. *Chiracanthium inclusum* had an average of 57 eggs per egg mass, whereas, *H. velox* and *T. volutus* had an average of 110 and 56 eggs per egg mass, respectively.

Selective Toxicity of Some Pesticides to H. velox

Fourteen different pesticides commonly used in lime orchards were included in the toxicity tests under laboratory conditions. Nine pesticides (i.e. avermectin, azinphosmethyl, carbaryl, chlorpyrifos, dicofol, ethion, imidacloprid-admire, imidacloprid-provado, and copper) were tested using surface coating method and four pesticides (i.e. azadirachtin, *Bacillus thuringiensis*, diflubenzuron, combination of petroleum oil and avermectin, and petroleum oil alone) were tested using a dipping method. Among the nine pesticides tested using the surface coating method, the five broad-spectrum insecticides were all highly toxic to *H. velox* causing 100% mortality even at the lowest concentration. Avermectin and imidacloprid-provado had moderate toxicity; whereas, imidacloprid-admire and copper fungicide caused the lowest percent mortality (10-30%) even at the highest concentration. In the dipping method, petroleum oil exhibited a low toxicity on *H.*

velox, 15% mortality from the highest concentration, five percent from the simulated field rate (SFR), and 0% from the lowest concentration. However, combining petroleum oil with Avermectin, a synergistic effect elevated the toxicity to moderate. The naturally derived products, i.e. azadirachtin (neem extracts), *Bacillus thuringiensis* (insecticidal bacterium) and diflubenzuron (insect growth regulators) showed low impact to *H. velox*. Less than 30% mortality was recorded at the highest concentration for all these products.

Conclusions and Recommendations

In this research, significant findings were obtained on the existence of a rich community of predatory arthropods (i.e. green lacewings, coccinellids, ants, and various species of spiders) in lime orchards at Homestead, Florida. A study comparing the different methods in sampling predatory arthropods provided useful data in selecting an efficient method to sample the different groups of predatory arthropods. The data gathered in sampling the predatory arthropods in sprayed and nonsprayed lime orchards confirmed the probable nontarget effect of the different pesticides used in the orchards. The direct effect of some of these pesticides on spiders was verified in laboratory bioassays. Studies on predation assessment, predatory behavior, and detailed biology of the hunting sac spiders provided useful data to better understand the role of these spiders in the overall management of CLM.

The diversity of the predatory spiders in lime orchards could help in regulating the increase of arthropod pest populations; however, most of these useful spiders are still unknown to most farmers and pest managers. To help accomplish this identification objective, we developed an identification key to 16 predatory spiders of lime in Homestead, Florida. Also, included in the identification key are photographs of the most commonly encountered species in the orchards.

After identifying the spider species, estimating of the abundance of each of these spider species is the next step to accomplish. This will help in measuring the impact of predation on prey population. There are two ways to measure abundance: absolute density (number of organisms per unit area or volume) and relative density (density of one population relative to another population). According to Krebs (1989), relative density may be adequate for many ecological problems and it should always be used when adequate because it is much easier and cheaper to determine than absolute density. In the sampling experiments included in this study, the abundance was measured using relative density.

Comparison of the sampling methods indicated that the choice of sampling method depends on the species of interest. For instance, spider species in the hunting group were collected frequently using the visual method followed by the shake-cloth method, whereas, most of the species in the web-building group were collected by the three sampling methods with similar frequencies. The difference in the efficiency of the sampling methods may be explained by the retreating habits of the different spider species. For instance, the hunters (i.e. *C. inclusum*, *H. velox* and *T. volutus*) retreat in such a concealed manner such that shaking and suctioning will not dislodge them from the retreat nest. However, this retreat nest is easily noticeable by visual examination. In the web-building group, the orb-weavers retreat in an open space, which makes them accessible by either of the three sampling methods. The space-web spiders (i.e. *Theridion* sp.) hide in a delicate sheet web, being easily dislodged by plant shaking or detected by visual examination, but protected from suctioning by the DVAC. The sheet web is easily noticeable by visual examination. A strategy for sampling spiders would be to use the most precise and affordable sampling method. The abundance of the soil surface-dwelling spiders was not determined in this research. Thus, the abundance and role of these species as mortality factors of CLM should be determined in lime orchards.

The biological and predatory behavior studies of the three species of hunting spiders (i.e. *C. inclusum*, *H. velox* and *T. volutus*) showed their potential as predators of CLM under outdoor conditions. Nevertheless, whether spiders are effective predators of CLM on lime orchards cannot be answered conclusively yet. More studies should be conducted in other geographical areas to further examine the efficiency of the spider species known to feed on CLM. Future investigations should determine the best predator-prey ratio for managing the population of CLM. The effect of the spider assemblage and their compatibility with other natural enemies should also be checked. For instance, field experiments combining the different spider species and the other natural enemies with known association on CLM (i.e. green lacewings, ants and parasitoids) may elucidate the importance of each biotic mortality factor.

Predation assessment by spiders under field conditions is inherently difficult to study; however, the existence of specific predation marks produced by the three species of sac spiders on CLM will make it possible to quantify their predation. One drawback in this system is that one of the predation marks made by the sac spiders on CLM larvae is somewhat similar to the feeding made by *Pnigalio minio*, an ectoparasitoid of CLM, which can easily be confused during field counts. A way to overcome this predation assessment problem is by using the predator gut content analysis. The preliminary result of the gut content analysis using PAGE showed the potential of this method in studying the predator-prey relationship in the field. A difficulty, which may arise, is the number of different preys consumed by the spiders as they are known to be generalist predators. It is therefore necessary to co-electrophorese all suspected prey species with the predators on the same gel.

The assessment of spiders as mortality factors of the eggs and adults of CLM is not covered in this research Further studies should test the possibility that the three species of sac spiders could also attack eggs and adults of CLM Previous studies on other species of sac spiders (i e *Aysha gracilis*, *Chiracanthium mildei* and *Trachelas deceptus*) showed that they feed on eggs of lepidopteran pests (Mansour et al. 1987, Carroll 1980) There is also a possibility that the orb-weaving spiders can attack adults of CLM that will be trapped on their webs

Rearing of the spiders in both the artificial diets and natural diets allowed us to study the biology of the most important spider species in lime orchards. Moreover, our success in rearing the three species of sac spiders from egg to maturity using the artificial combination diet may open the possibility of mass rearing the most important species of spiders for possible release in the field Therefore, it is worthwhile to further examine the efficiency of the artificial combination diet in mass rearing of spiders Different proportions of the ingredients of the artificial combination diet must be tried to achieve better survival and reproduction of the spiders.

In general, spiders appear to possess many attributes that make their presence in the lime orchards desirable. Being a complex of many diverse species, they tend to fill many predaceous niches in the orchards or prey more easily than a single predator In particular, the three species of sac spiders prey almost throughout all stages of their development on CLM larvae and prepupae and they are relatively long lived Thus, given their abundance and predation potential, they possibly play an important role as natural enemies of CLM in lime orchards

APPENDIX A
KEY TO THE PREDATORY SPIDERS IN LIME ORCHARDS IN HOMESTEAD, FLORIDA

(see Figures A-13 and A-14 for the generalized external morphology of spider)

1 Tarsi 2-clawed with or without claw tufts 2

1' Tarsi 3-clawed, claw tuft absent although spurious claws present 14

2 Eyes arranged in 3 or 4 distinct rows (family **SALTICIDE**) 3

2' Eyes arranged in 2 rows 8

3 Eyes in 4 distinct rows, spiders translucent green .... ***Lyssomanes viridis* (Figure A-1)**

3' Eyes in 3 distinct rows, spiders not translucent green 4

4 Labium as long as or longer than wide, cephalothorax widest posteriorly, (PLE) beyond midlength of cephalothorax with a steep declivity just beyond **PLE** .... ***Zygoballus rufipes***

4' Labium and cephalothorax not as above. 5

5 Carapace with side strongly curved, PME twice as far from PLE as ALE, ocular hair tufts present; male chelicerae iridescent; most carapace covered with white hairs, narrow area on each side near eyes lack white hairs, abdomen dorsal coloration varies from orange-brown to brownish black, relatively large spider, female 13-19 mm and male 9 mm .... ***Phidippus regius* (Figure A-2)**

5' Carapace not strongly curved laterally, PME not quite so near to ALE, without tufts of hair in eye region, body coloration not as above 6

6 ,Iridescent or metallic scales spread all over the body, front sternum as wide as base of labium ... *Metaphidippus vitis*

6' Lacking iridescent or mettalic scales front sternum narrower than base of labium ... 7

7 At least legs II and IV white and translucent patch of long spatulate hairs on ventral retromargin of patella and femur I and below PME (also called pencil hairs), male oftenwith elongate chelicerae projecting anteriorly ... *Hentzia palmarum* **(Figure A-3)**

7' Legs II and IV pigmented, long spatulate hairs absent on patella and femur I and below PME chelicerae of male never elongate ... *Metacyrba* **sp.**

8 Ventral abdominal tracheal spiracle adjacent to spinnerets... ... 9

8' Tracheal spiracle nearer middle of abdomen or epigastric furrow or tracheal spiracle located considerably anterior to the spinnerets, most often midway between spinnerets and epigastric furrow **(family ANYPHAENIDAE)** ... 10

9 Legs arranged prograde, first pair directed forward, some spiders with abdominal scutum. ... 11

9' Legs arrange laterigrade, first pair directed laterally, abdominal scuta always lacking **(family THOMISIDAE)** ... 12

10 Tracheal spiracle much closer to epigastric furrow than to spinnerets ... *Hibana velox* **(Figure A-4)**

10' Tracheal spiracle roughly midway between epigastric furrow and spinnerets ... *Teudis mordax*

11 Tibia I with 1 - 3 pairs of ventral macrosetae, body commonly pale yellow to pale green but may change depending on the prey eaten, all legs also pale yellow **(family CLUBIONIDAE)** .. ***Chiracanthium inclusum*** **(Figure A-5)**

11' Tibia I lacking ventral macrosetae; sternum and carapace reddish brown covered with tiny punctures, abdomen light gray, all legs darker **(family CORRINIDAE)** ***Trachelas volutus*** **(Figure A-6)**

12 Female carapace white to dull yellow with median X-shaped marking, male carapace dull to bright yellow margins with narrow red seam ***Misumenops celer***

12 Female and male carapace not as above 13

13 Carapace with dark longitudinal bands and armed with the usual long spines ***Misumenops bellulus***

13' Carapace without dark bands, embolus originating at the distal end of the bulb .. .. ***Misumenops oblongus***

14 Each tibia and metatarsus of legs I and II with a row of long spines to the prolateral surface with shorter curved spines in the intervals **(family MIMETIDAE)** ***Mimetus*** sp.

14' Legs without this arrangement of spines 15

15 Eyes two rows (four, four), posterior row of eyes only slightly recurved and appears in one row; one row of trichobothria on each tarsus, male pedipalp with tibial apophysis, eggs carried by the female on ventral surface of cephalothorax held by chelicerae and pedipalps **(family PISAURIDAE)** .. .. .. *Dolomedes* sp

15' Eyes in three rows (four, two, two), posterior eye row strongly recurved, usually two rows of trichobothria on tarsi, male pedipalp without tibial apophysis, eggs carried by the female behind spinnerets; young carried on female's dorsum, **(family LYCOSIDAE)** ... *Pardosa* sp.

16 Colulus present ... 22

16' Colulus absent, consisting of 2 fine setae or may be present in some genera **(family THERIDIIDAE)** ... 17

17 Abdominal venter with red pale orange hourglass, lateral eyes separated by their diameter or more, cheliceral margins without teeth, internal genitalia with dumbbell shaped spermathecae, palpus with coiled embolus, ... ***Latrodectus geometricus***

17' Abdominal venter lacking hourglass , lateral eyes contiguous or slightly separated, chelicerai margins toothed, genitalia not as above... ... 18

18 Male eye or clypeal region swollen and projecting, or grove below eyes, female abdomen higher than long, with humps extending beyond spinnerets or thread-shaped, often with silver spots, third tarsal claw often longer than paired claws, no comb setae on tarsi IV, but serrated bristles on prolateral side of tarsus IV, some found in orb-web of other spiders ... ***Argyrodes nephilae***

18' Male eye or clypeal region neither swollen and projecting nor with groove below eyes, female abdomen oval or spherical, never silver spots, third tarsal claw smaller than paired claws, comb setae on tarsi IV ... 19

19 Abdomen not longer than wide, oval to spherical or wider than long, without tubercle or point above and posterior to spinnerets ... 20

19' Abdomen longer than wide high with tubercle or point above and posterior to spinnerets, palpus with all sclerites present .... ***Chrysso pulchra***

20 Female abdomen wider than long, each lateral point dark and with prominent dorsal white spot, carapace with wide black longitudinal band, palpus simple with twisted embolus on distal tip of bulb .... ***Theridula gonygaster***

20' Abdomen, if wider than long, marked otherwise, carapace lacking wide black longitudinal band, if male has simple palpus, embolus is straight, not twisted 21

21 Males with sclerotized ring around abdomen encircling pedicel and covering epigastric area, abdomen often constricted in middle, male palpus less 4 mm length, females with small eyes and projecting clypeus. .... ***Coleosoma floridanum***

21' Male eye region never modified, usually more than 1 5 mm long rarely orange in color; no scutum on abdomen, egg sac not carried by spinneret .... ***Theridion*** sp (Figure A-7)

22 Stridulating structures usually present on side of chelicerae **(family LINYPHIIDAE)** .... *Epirigone banksi*

22' Stridulating structures absent 23

23 Median apophyses absent epigynum flat with no external plate, web type usually horizontal or oblique orb web **(family TETRAGNATHIDAE)** 24

23' Median apophysis present epigynum 3-dimensional many species with scape, web type usually a vertical orb (family **ARANEIDAE)** 26

24 Abdomen cylindrical or tapering elongate, 2-3 times as long as wide (measured at mid point) . . . . ***Leucauge venusta***

24' Abdomen globular or oval less than twice as long as wide. 25

25 Chelicera enlarged pointed 5-9 teeth on margins, endites divergent, truncate distally, epigynum absent in adult female, latter lacking distal tufts on legs male embolus and conductor directed distally, PE equidistant, orb-web horizontal . . . . ***Tetragnatha guatemalanensis***

25' Chelicerae normal, 3 teeth on margin endites convergent, obliquely truncated mesally epigynum present, female large (19-34 mm), distal tufts on femora and tibiae I, II, and IV, male smaller (4 6 - 10 5 mm), embolus and conductor directed at right angles to long axis of the palpus, PME closer to each other than to PLE, orb-web vertical . . . . ***Nephila clavipes* (Figure A-8)**

26 Spinnerets without sclerotized ring, abdomen not heavily sclerotized, with or without spines 27

26' Spinnerets surrounded by sclerotized ring, abdomen heavily sclerotized, always with spines . . . . ***Gasteracantha cancriformis* (Figure A-9)**

27 Scape smooth, never torn off 28

27' Scape wrinkled, sometimes torn off 29

28 Abdomen with 4 black longitudinal lines, median pair over heart, joining posteriorly, outer lines enclose dark brown area bounded laterally by white . . . . ***Acacecia hamata* (Figure A-10)**

28' Abdomen marked otherwise, scape long and slendar, tip closer to spinnerets than to the base of epigynum . . . . ***Eriophora ravilla* (Figure A-11)**

29 Abdominal venter with 2 pairs of white spots (rarely lines or brackets) separated by median black areas, base of epigynum barely wider than scape (at most, twice width) and less sclerotized, scape spatula-shaped *Neoscona arabesca* (Figure A-12)

29' Abdominal venter of abdomen marked otherwise, base more sclerotized than scape and at least three times its width. *Araneus* sp

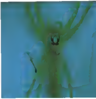

Figure A-1 *Lyssomanes viridis*

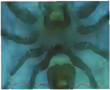

Figure A-2 *Phidippus regius*

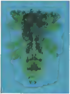

Figure A-3. *Hentzia palmarum*

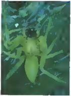

Figure A-4. *Hibana velox*

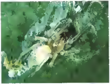

Figure A-5. *Chiracanthium inclusum.*

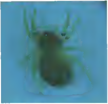

Figure A-6. *Trachelas volutus.*

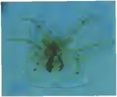

Figure A-7 *Theridion* sp

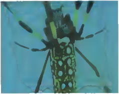

Figure A-8 *Nephila clavipes*

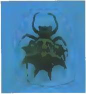

Figure A-9 *Gasteracantha cancriformis*

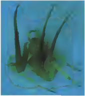

Figure A-10 *Acacesia hamata*

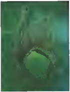

Figure A-11 *Eriophora ravilla*

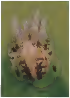

Figure A-12 *Neoscona arabesca*

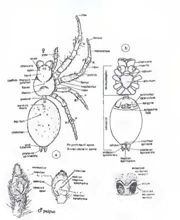

Figure A-13 External morphology of spider showing the dorsal view with male and female palpi (a) and ventral view with epigynal structure (b). [modified from Barrion & Litsinger 1995]

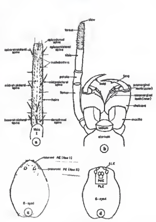

Figure A-14 Leg components (a), mouthparts (b), eye morphology and pattern showing eight type (c), and six type (d). [*modified from* Barrion & Litsinger 1995]

APPENDIX B

SURVIVAL OF HUNTING SPIDER, *HIBANA VELOX* (ARANEAE: ANYPHAENIDAE), RAISED ON DIFFERENT ARTIFICIAL DIETS

(Accepted for publication in the Journal of Arachnology, November 28, 1998)

Spiders occupy an important part of the overall predatory arthropod fauna in different terrestrial ecosystems (Riechert 1974, Riechert & Lockley 1984). They are also known to play an important role in the regulation of pest species in agriculture (Whitcomb et al. 1963, Dondale et al. 1979, Dean et al. 1982, Mansour et al. 1982, Culin & Yeargan 1983, Mansour et al. 1983, Oraze & Grigarick 1989, Riechert & Bishop 1990, Barrion & Litsinger 1995). Baseline information on life history and biology are fundamental for ecological work and are also important to further investigate the potential of spiders as biological control agents; however, life history studies have been done on very few species of spiders. One reason is the lack of reliable rearing methods to determine life histories and other biological data directly from laboratory cultures. Another reason is the lack of appropriate artificial diets, and behavioral cues from the prey to initiate attack and feeding (Riechert & Luczak 1982). Moreover, it appears that most spiders feed on a variety of insect prey species to obtain the optimum nutrition for survival and reproduction (Greenstone 1979, Uetz et al. 1992). The need to rear different insect species as prey makes it especially difficult to culture spiders in the laboratory. Formulation of artificial diets would greatly facilitate laboratory rearing of spiders; however, knowledge on the complete nutritional requirements for spider is necessary. Recently, it was reported that some species of wandering spiders are facultative nectar feeders (Taylor & Foster 1996). This could explain the success of some previous works (Peck & Whitcomb 1968, Whitcomb 1967) on rearing spiders using artificial diets This finding of nectivorous feeding behavior inspired us to compare different artificial diets for the survival of spiders For this study, the hunting spider (Anyphaenidae), *Hibana (=Aysha) velox* (Becker 1879), was selected because it was found to be the dominant species in lime (*Citrus aurantifolia* [Christm.] Swingle1914) groves in south Dade County, Florida. Also, its spiderlings were observed to feed on the larvae of citrus leafminer, *Phyllocnistis citrella* Stainton 1856 Voucher specimens of *H velox* and *P citrella* are deposited at the Division of Plant Industry (DPI) Gainesville, Florida.

To test the effects of the different artificial diets on the survival of *H velox*, egg sacs were collected in the field and brought into the laboratory and kept until the eggs hatched The resulting offsprings were used for the experiment Each spiderling was maintained in a separate container as described by Peck & Whitcomb (1968) with some modifications to prevent cannibalism Instead of glass tubing with both ends open, common laboratory glass vials (15 mm diam x 60 mm long) were utilized The open end was plugged with cotton through which a stemmed cotton swab had been inserted The cotton swab inside the glass vial was saturated with the artificial diet by dipping Three different artificial diets were included in the experiment 30% sucrose solution (cane sugar, Publix Supermarket Inc , Lakeland, FL), milk + yolk mixture (1 fresh chicken egg yolk 1 cup homogenized milk), and soybean (non-dairy beverage) water served as the control Nutritional composition of the milk plus yolk and soybean diets are provided (Table 1) Twenty spiderlings were included for each artificial diet Two replications in time were prepared and kept at 27°C in different rearing chambers, one at 45% RH and the other at 80% RH The two conditions of RH were chosen based on previous work by Peck & Whitcomb (1968) and Taylor & Foster (1996)

At 45% RH, all the spiders on all of the diets died in ≤ 30 days after the start of the experiment (Table 1) On the contrary, Peck and Whitcomb (1968) reported best survival [42 days for *Chiracanthium inclusum* (Hentz 1847) and 90 days for *Gladicosa* (reported as *Lycosa*) *gulosa* (Walckenaer, 1837] when the spiders were kept at 45% RH There was no significant difference for the age at death of *H velox* on different diets. The mean age at death of the spiders kept at 45% RH was 13 days (range, 7-18) on soybean diet, 10 days (range, 8-11) on milk + yolk diet, 12 days (range, 7-16) on 30% sucrose solution, and 11 days (range, 7-14) on water Spiders kept at 80% RH survived longer, especially spiders on soybean and milk plus yolk diets After 30 days, the percent survival of spiders on soybean diet (82 5%) was significantly higher ($P < 0\ 05$) than on milk + yolk diet (46%) Spiders raised on 30% sucrose solution and water did not survive for the duration of the experiment The mean age at death of spiders on sucrose solution was 14 days (range, 5-21), whereas, for spiders on water, it was 11 days (range, 8-12) On both soybean and milk + yolk diets, the first mortality occurred at 6 days from the start of the experiment. A drastic increase in mortality was observed on milk + yolk diet from day 6 to day 16 from the start of the experiment, the survival endpoint was reached at day 17 (Fig 1) Mortality was less on soybean diet, the survival endpoint was at day 12 (Fig 2) The single mortality at day 21 was due to fungal contamination

Although the percent survival on soybean diet was significantly higher ($P < 0\ 05$) than on milk+yolk diet, the development of spiders seemed to be delayed This observation was based on percent molting, time of molting, and carapace width of the spiders. Spiders raised on milk + yolk diet underwent two molts 30 days from the start of the experiment (Fig. 1). The earliest molt was 6 days from the start of the experiment; the mean age at first molt was 17 days (range, 6-30). The mean age at second molt was 25 days (range, 20-30). On soybean diet, the molting of the spiders was late compared to the spiders on milk + yolk diet. The first molt was at 24 days and only 40 % of the surviving spiders molted 30 days from the start of the experiment (Fig. 1). The average carapace width of spiders raised on milk plus yolk diet was 0.70 mm (range, 0.50-0.85), whereas, spiders on soybean diet had an average carapace width of 0.50 mm (range, 0.35-0.58). In general, the carapace width of spiders on milk+yolk diet was more than 1/4 greater than that of spiders on soybean diet. These findings suggest the importance of supplying more complete nutritional requirements when rearing spiders using artifical diets. The soybean diet is devoid of cholesterol (Table 1) which is the common source of sterol. It was reported that cholesterol is a precursor of ecdysone, the molting hormone (Foelix 1982). This may explain the delayed development of spiders on soybean diet. The milk + yolk diet has a high level of cholesterol, such that spider development seems to progress normally. Nevertheless, the high level of carbohydrates in the soybean diet (Table 1) suggests that carbohydrate could be an important component of the artifical diet for spiders. Carbohydrates are the major energy source important for survival or longevity of any arthropod species (Singh 1984). In this experiment, we observed that the percent survival of spiders on soybean diet was almost twice that on milk + yolk diet. Furthermore, the drastic increase in mortality of spiders on milk plus yolk diet in the first two weeks of rearing the spiders may be avoided if enough carbohydrate is available at that stage of development From the result of this experiment, we can hypothesize that a combination of soybean and milk + yolk diets could provide more balanced nutritional requirements for wandering spiders. Thus, an experiment to assess the performance of combining soybean and milk + yolk diet on spider survival and development is underway

Amalin, D M , TREC-IFAS, SW 280th St., Homestead FL, 33031, Reiskind, J., Dept of Zoology, Univ of Florida, Gainesville, FL 32611, McSorley, R., Bldg 970 Hull Road, Dept of Entomology and Nematology Univ of Florida, Gainesville, FL 32611, Peña, J, TREC-IFAS, SW 280th St , Homestead, FL, 33031

[1] This manuscript is Florida Agricultural Experiment Station Journal Series No R-05542

LITERATURE CITED

Barrion, A T & J A. Litsinger 1995   Riceland Spiders of South and Southeast Asia. CAB International, Wallingford, UK, 701 p

Culin, J D & K V Yeargan. 1983   Comparative study of spider communities in alfalfa and soybean ecosystems: Foliage-dwelling spiders. Ann. Entomol Soc.America, 76 825–831

Dean, D A., W L Sterling & N V Horner   1982   Spiders in eastern Texas cotton fields J Arachnol , 13 111–120

Dondale, C D , B Parent, & D Pitre. 1979   A 6-year study of spiders (Araneae) in a Quebec apple orchard. Can Entomol , 111 377–380

Foelix R. 1982   Biology of Spiders. Harvard University Press, Cambridge, MA., 306 p

Greenstone, M H.1979   Spider feeding behaviour optimizes dietary essential amino acid composition   Nature 282 501–503

Mansour, F , J W Ross, G B Edwards, W H Whitcomb, & D Richman   1982   Spiders of Florida citrus groves Fla. Entomol., 65 514–522

Mansour, F A., D B Richman, & W H Whitcomb 1983 Spider management in agroecosystems habitat manipulation Environ Manag 7 43–49

Oraze, M J & A.A Grigarick 1989 Biological control of aster leafhopper (Homoptera Cicadellidae) and midges (Diptera Chironomidae) by *Pardosa ramulosa* (Araneae. Lycosidae) in California rice fields J Econ. Entomol , 82 745–749

Peck, W B & W H Whitcomb 1968 Feeding spiders on artificial diet Entomol News, 79 233–236

Reichert, S E 1974 Thoughts on the ecological significance of spiders BioScience, 24.352–356

Reichert, S E & J Luczak 1982 Spider foraging Behavioral responses to prey Pp 353–384 In Biology of Spider Communication Mechanisms and Ecological Significance. (P.N Witt & J Rovner, [eds]). Princeton University Press Princeton, NJ 440 p

Reichert, S E & L Bishop 1990 Prey control by an assemblage of generalist predators spiders in garden test systems Ecology, 71 1441–1450

Reichert, S E & T Lockley 1984 Spiders as biological control agents Ann Rev Entomol , 29 299-320

Singh, P 1984 Insect diets Historical developments, recent advances, and future prospects Pp 32–44, In Advances and Challenges in Insect Rearing. (E G King and N C. Leppla, [eds]), Agricultural Research Service (Southern Region), U S Department of Agriculture, New Orleans, L.A. 306 p

Taylor, R.M & W A. Foster 1996 Spider nectarivory American Entomol , 82–86

Uetz, G W , J Bischoff, & J Rover 1992 Survivorship of wolf spiders (Lycosidae) reared on different diets. J Arachnol , 20.207–221

Whitcomb, W H. 1967 Wolf and Lynx spider life histories. In. terminal report to National Science Foundation Univ of Arkansas. Division of Agriculture Dept. of Entomology Fayetteville AK 142 p

Whitcomb, W H , H. Exline, & R.C Hunter 1963 Spiders of the Arkansas cotton field Ann Entomol Soc. America, 56 653-660

Table 1 Nutritional composition of milk + yolk and soybean diets based on the manufacturer's nutritional analysis per 100 ml of media

Nutrient Composition	Milk plus Yolk[y]	Soybean[z] (non diary beverage)
Total fat	3.04 g	1.30 g
Saturated fat	1.30 g	0.0 g
Cholesterol	97.83 mg	0.0 mg
Sodium	82.61 mg	39.13 mg
Total carbohydrates	6.09 g	10.87 g
Sugars	5.22 g	6.52 g
Protein	6.04 g	2.61 g
Potassium	0.0 mg	126.09 mg
Vitamin A	348.00 IU	0.0 IU
Thiamin (B1)	0.0 mg	0.05 mg
Riboflavin (B2)	0.0 mg	0.03 mg
Niacin (B3)	0.0 mg	0.52 mg
Pantothenic Acid (B5)	0.0 mg	0.35 mg
Pyridoxine Hydrochloride (B6)	0.0 mg	0.05 mg
Folate (B9)	0.0 mg	0.02 mg
Vitamin C	0.52 mg	0.0 mg
Vitamin D	43.48 IU	0.0 IU
Biotin (Vitamin H)	0.0	0.003 g
Calcium	0.14 g	0.03 g
Iron	0.31 mg	0.31 mg
Phosphorous	0.11 g	0.04 g
Magnesium	0.0 mg	17.4 mg
Zinc	0.0 mg	0.26 mg

[y] Composition from product labels on milk and eggs. Publix Super Market Inc., Lakeland, FL 33802

[z] Composition from product label. Edensoy ® Eden Foods, Inc. Clinton, Michigan 49236.)

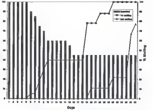

Figure 1 Percent survival and molting of Hibana. velox using milk plus yolk diet as artifical diet

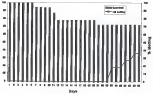

Figure 2 Percent survival and molting of Hibana. velox using soybean as artificial diet.

APPENDIX C
PREPARATION OF BANANA MEDIUM FOR MASS REARING OF *DROSOPHILA MELANOGASTER* (BASED ON YOON, 1985)

Composition (to make 1000 ml medium).

Banana (without skins)	300.0 g
Yeast (dry Brewer's)	22.4 g
Gelrose Agar	12.0 g
Water	1000 ml
Corn syrup ("Karo")	26.6 ml
Malt (powdered)	0.0002 g
Vinegar (distilled)	3.6 ml
Ethanol (95%)	3.6 ml

Diet Preparation.

- Blend the agar, yeast, and chopped banana with ¾ of the water to make a pourable mixture
- Pour banana mixture into cooking vessel (i.e. Erlenmeyer flask), add remainder of the water and stir well
- Cook in the microwave for 5 minutes, then add Karo syrup, malt, and the rest of the chemicals, stir to mix the medium
- Dispense the medium into sterilized glass vials using sterilized beaker

Precaution

All equipment, tools, cotton balls, filter paper must be sterilized at 1.1 kg cm^2 at 120 °C for 20 min. Mixing and dispensing of the medium must be done under a fume hood

REFERENCES CITED

Abbot, W S 1925 A method for computing the effectiveness of an insecticide. J Econ Entomol. 18 265–267

Agnew, C W , & J W Smith Jr 1989 Ecology of spiders (Araneae) in a peanut agroecosystem Environ Entomol 18 30–42

Agnew, C W , & J W Smith Jr 1989 Ecology of spides (Araneae) in a peanut agroecosystem Environ. Entomol 8 30–42

Aguilar, F 1968 Araneida frecuentes en el algodonero Rev Peru. Entomol 11 92–95

Aguilar, P G 1965 Notas sobre las arañas en el campo cultivado Rev Peru Entomol 8 81–83

Aguilar, P G 1974 Arañas del campo cultivado – 1 poblacion de araneidos en algodonales de Canete, Huaura y Rimac (Spiders of crop fields – 1 populatios of araneids in cotton plantations in Canete, Huaura, and Rimac) Rev Peru. Entomol 17 21–27

Ahmad, S K 1988 Chemical control of citrus leafminer on citrus. Pak. J Agric. Res. (Lahore) 9:271–273

Ali, A.D., & J S Hartin. 1988 A faunal survey of spiders associated with *Pinus radiata* in a Southern California farm. J Arachnol 16.269–272.

Almquist, S 1981 Spiders and harvestmen in strawberry fields in southern Sweden. Entomol Tidskr 102 159–162

Altieri, M A , & D K Letourneau 1984 Vegetation diversity and insect pest outbreaks. Critical Reviews in Plant Sciences 2 131–169

Amalin, D M , & A.A. Barrion 1992 Spiders of potato in the Philippines Philipp Agric 73 179–184

Amalin, D.M., J E Peña, & R. McSorley 1996 Abundance of spiders in lima groves and their potential role in suppressing the citrus leafminer population p 72 In. M A. Hoy [ed.], Proceedings, International Meeting Managing the Citrus Leafminer, 22–25 April 1996, Orlando, Florida. University of Florida, Gainesville, Florida.

Amalin, D M , J E Peña, & R. McSorley 1996 Spiders for leafminer biocontrol Conference Notes The IPM Practitioner 18 15

Amalin, D M , & E A Vasquez. 1993 A Handbook on Philippine Sweet Potato Arthropod Pests and their Natural Enemies. International Potato Center, Los Baños, Laguna, Philippines 82 p

Amalin, D.M., E.A. Vasquez, & P Vander Zaag. 1991 Arthropods of sweet potato in the Philippines Philipp Agric 74.39–50

Ando, T , K. Taguchi, M Uchiyama, T Ujiye, & H Kuroko 1985 (7Z-11Z)-7,11-hexadecadienal sex attractant of the citrus leafminer moth, *Phyllocnistis citrella* Stainton (Lepidoptera Phyllocnistidae) Agric Biol Chem (Tokyo) 49 3633–3635

Anonymous. 1959 Illustrated insect larvae of Japan Hokuryukou , Tokyo 714 p

Anonymous. 1979 Trials on the protection and use of the spiders in large paddy fields. Biology Department, Hunan Teachers College, Changsa Hunan, People's Republic of China (in Chinese)

Argov Y , & Y Rossler 1996 Introduction, release and recovery of several exotic natural enemies for biological control of the citrus leafminer, *Phyllocnistis citrella*, in Israel Phytoparasitica 24 33–38

Ashikbayev, N.Z 1973 The life forms of spiders (Araneae) inhabiting wheat fields in the Kustanay region Entomol Rev 52 335–341

Atwal, A.S , & G C Verma. 1970 Studies on the control of citrus leafminer, *Phyllocnistis citrella* Stainton (Gracillariidae) J Res Punjab Agric. Univ (Ludhiana) 7 55–57

Auerbach, M & P Simberloff 1989 Oviposition site preference and larval mortality in leafmining moth Ecological Entomol 14 131–140

Awate, B G , L M Naik, & U M Raut. 1976 Control of citrus leafminer (*Phyllocnistis citrella* Stainton Gracillariidae Lepidoptera) with modern synthetic insecticides. J Plant Crops 4 35–36

Ayoub, M A. 1960 *Phyllocnistis citrella* Stainton, a main citrus pest in Saudi Arabia (Microlepidoptera Lyonetiidae) Bull Soc. Entomol Egypt (Cairo) 44 387–391

Ba-Angood, S A.S 1977 A contribution to the biology and occurrence of the citrus leafminer *Phyllocnistis citrella* Stainton, in Sudan. Z Angew Entomol 83 106–111

Ba-Angood, S.A.S 1978 On the biology and food preference of the citrus leafminer, *Phyllocnistis citrella* Stainton in PDR of Yemen. Z Angew Entomol 86 53–57

Badawi, A. 1981 Studies on some aspects of the biology and ecology of the citrus butterfly *Papilio demoleus* L in Saudi Arabia (Papilionidae, Lepidoptera) Z Angew Entomol 91 286–292

Badawy, A. 1968 The control of *Phyllocnistis citrella* Staint., a citrus leafminer in the Sudan (Lepidoptera. Gracillariidae) Bull Soc. Entomol Egypt (Cairo). Econ. Ser 2 129–130

Badswy, A. 1969 The morphology and biology of *Phyllocnistis citrella* Stainton, a citrus leafminer in Sudan (Lepidoptera Tineidae) Bull Soc. Entomol Egypt 51 95–103

Bailey, C L , & H L Chada. 1968 Spider populations in grain sorghums Ann. Entomol Soc. Am. 61 567–571

Balogh, J , & J Loksa. 1956 Untersuchungen über die Zoozönose Luzernefeldes Acta Zool Acad Sci Hung 2 17–114

Barbosa, J T , G M Rascado, & M L Filho 1979 Population fluctuation of sugarcane froghopper, *Mahanarva posticata* Stal, 1855 and its natural enemies in Campos, R J , in 1977 Ann Soc Entomol Bras 8 39–46

Barrion, A.A , & L.D Taylo 1989 Survey of predatory spiders in citrus orchards of the Laguna, Batangas and Ma–a, Davao City, Philippines Philipp Agric. 72 73–78

Barrion, A.T 1982 Spider Fauna in Rice Agroecosystems M S thesis University of the Philippines, Los Banos.

Barrion, A.T 1992 Illustrated Guide to Rice Integrated Pest Management International Rice Research Institute. Los Banos, Philippines

Barrion, A.T , & J.A Litsinger 1994 Taxonomy of rice insect pests and their arthropod parasites and predators. pp 13–362 E.A. Heinrichs (ed). In Biology and Management of Rice Insects Wiley Eastern Limited, London 779 p.

Barrion, A.T., & J A. Litsinger 1995 Riceland Spiders of South and Southeast Asia. Centre for Agriculture and Biosciences International, Wallingford, Oxon, England 700 p

Barroga, S F 1968 Biological notes and control of citrus leafminer (*Phyllocnistis citrella* Stainton) affecting citrus seedlings Philipp J Plant Ind 33 17–29

Basedow, T. 1973 Der Einfluss epigäischer Raubarthropoden auf die Abundanz phytophager Insekten in der Agrarlandschaft. Pedobiologia (Jena) 13 410–422

Batra, R.C , & G S Sandhu. 1980 Soil systemic granular insecticides for chemical control of citrus leafminer, *Phyllocnistis citrella* on Kinnow mandarin. Pestology (Bombay) 4 13–14

Batra, R.C., & G S Sandhu. 1981a. Foliar spraying and soil drench treatments of insecticides for the control of citrus leafminer *Phyllocnistis citrella* Ind J. Entomol (New Delhi) 43 83–86

Batra, R.C , & G S Sandhu 1981b Comparison of different insecticides for the control of citrus leafminer *Phyllocnistis citrella* in the nursery Pesticides (Bombay) 15 5–6

Battu, G S , & B Singh. 1975 A note on spiders predatory on the insect pests of cotton Sci and Cult 41 212–214

Beattie, G A.C 1992 The use of petroleum spray oils in citrus and other horticultural crops Proc 1st Nat Conf Aust Soc. Hortic Sci , Sydney, 1991 pp 351–362

Beattie, G A.C , & D Smith 1993 Citrus leafminer Agfact H2 AE 4, second Ed NSW Agriculture, Orange, Australia 6 p

Beattie, G A.C , Z M Liu, D M Watson, A.D Clift, & L Jiang 1995 Evaluation of petroleum spray oils and polysaccharides for control of *Phyllocnistis citrella* Stainton (Lepidoptera. Gracillariidae) J Aust Entomol Soc. 34 349–353

Benz, G , & M Nyffeler 1980 Ecology of spiders in meadows, near Zurich (Switzerland) Proc Int. Arachnol Congr , 8th, Vienna, pp 121–125

Beyer, R. 1981 Zur Dynamik der Spinnen– und Weberknechtfauna auf einer Kulturfläche mit wechselndem Pflanzenbestand im Verlaufe von 5 Jahren im Raum Leipzig Faun Abh Mus.Tierk Dresden 8 119–130

Bhumannavar, B S , & S P Singh 1983 Studies on population dynamics of citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera Phyllocnistidae) Entomon (Trivandrum) 8 397–400

Bierl, B A., M Beroza, R.T Staten, P.E. Sonnet, & V Adler 1974 The pink bollworm sex attractant J Econ Entomol 67 211–216

Bilsing, S W 1920 Quantitative studies in the food of spiders Ohio J Sci 20 215–260

Bindra, O S 1957 Insect pests of citrus and their control Ind J Hort. (Sabour) 14 89–98

Bishop A.L 1979 The role of spiders in a cotton ecosystem. M S thesis, University of Queensland

Bishop, A L 1980 The composition and abundance of the spider fauna in south-east Queensland cotton Aust J Zool 28 699–708

Bishop, A.L 1981 The spatial dispersion of spiders in a cotton ecosystem. Aust. J Zool 29 15–24

Bishop, A.L., & P R.B Blood 1980 Arthropod ground strata composition of the cotton ecosystem in south-eastern Queensland, and the effect of some control strategies Aust. J Zool 28 693–697.

Blickenstaff, C C , & J L Huggans 1962 Soybean insects and related arthropods in Missouri Univ Missouri Agric. Exp Stn. Res Bull. 803 51

Bohlen, E 1973 Crop pests in Tanzania and their control P Parey, Berlin 142 p

Bosmans, R., & M.P Cotteme. 1977 Araignees rares ou nouvelles pour la faune belge des cultures. Bull Ann Soc. R. Belge Entomol 113 100

Boyer, W B , & W A. Duncans 1963 Soybean insect survey as used in Arkansas Coop Insect Rep 13 19–20

Brasse, D 1975 Die Arthropodenfauna von Getreidefeldern auf verschie–denen Böden im Braunschweiger Raum Pedobiologia (Jena) 15 405–414

Breene, R.G , D A Dean, & R L Meagher, Jr 1993a. Spiders and ants of Texas citrus groves Fla. Entomol 76 168–170

Breene, R G R L Meagher, Jr , & D A. Dean 1993b Spiders (Araneae) and ants (Hymenoptera Formicidae) in Texas sugarcane fields Fla Entomol. 76 645–651

Breymeyer A. 1967 Preliminary data for estimating the biological production of wandering spiders. pp 821–834 In K Petruncewicz (ed), Secondary Productivity of Terrestrial Ecosystems. Panstwowe Wydawn, Warszawa, Krakow

Breymeyer, A. 1978 Analysis of the trophic structure of some grassland ecosystems Pol Ecol Stud. 4 55–128

Bristowe, W S 1971 The World of Spiders New Naturalist, London.

Browning, H , & J E Peña. 1995 Biological control of the citrus leafminer by its native parasitoids and predators. Citrus Industry 76 46–48

Browning, H W , J.E Peña, & P A Stansly 1996 Evaluating impact of indigenous parasitoids on population of citrus leafminer pp 14–15 In M.A. Hoy (ed.), Proceedings, International Meeting Managing the Citrus Leafminer, 22–25 April 1996, Orlando, Florida. University of Florida, Gainesville, Florida.

Browning, H.W 1994 Early classical biological control on citrus pp 27–46 In D Rosen, F D Bennet, J L Capinera (eds), Pest Management in the Subtropics, Biological Control – A Florida Perspective Intercept, Andover, UK,

Browning, H.W , R.J McGovern, L K Jackson, D V Calvert, & W.F Wardowski 1995 Florida Citrus Diagnostic Guide Florida Science Source Inc., Lake Alfred, FL 244 p

Burgeous, W.J , & R.J Constantin 1995 Preliminary investigation into the control of citrus leafminer Louisiana Agric 38 13–14

Burleigh, J G , J H. Young, & R D Morrison 1973 Strip-croppings effect of beneficial insects and spiders associated with cotton in Oklahoma. Environ Entomol 2 281–285

Burnett, T 1958 Effect of host distribution on the reproduction of *Encarsia formosa* Gahan (Hymenoptera Chalcidoidea) Can Entomol 90 179–191

Butani, D K 1979 Insect pests of citrus and their control Pesticides (Bombay) 13 15–21

Byerly, K.F , A.P Gutierrez, R.E Jones, & R.F Luck. 1978 A comparison of sampling methods for some arthropod populations in cotton Hilgardia 46 257–282

Caleca, V , & G Lo Verde. 1996 Prove sull' attrattivit, di Z7, Z11–esadecadeinale su maschi di *Phyllocnistis citrella* Stainton (Lep Gracillariidae) in Sicilia. dati preliminari Phytophaga (Italy) 6 183–191

Campbell, C.W 1979 Tahiti lime production in Florida. Florida Coop Ext Service Bull 187

Carroll, D P 1980 Biological notes on the spiders of some citrus groves in central and southern California. Entomol News 91 147–154

Chant, D.A. 1956 Predaceous spiders in orchards in south-eastern England. J Hort. Sci 31 35–46

Chauvin, R. 1960 La faune du champs cultivé et surtout du champ de luzerne. Revue Zool Agric. 59 14–37

Chauvin, R. 1967 Die welt der Insekten Kindler Verlag, München 256 p

Chen, R., Y Chen, & M. Huang 1989 Biology of green lacewing *Chrysopha bonensis* and its predation efficiency on citrus leafminer, *Phyllocnistis citrella* pp 96–105 In Studies on the Integrated Management of Citrus Insect Pests. Academic Book & Periodical press, Beijing.

Cherrett, J M 1964 The distribution of spiders on the Moor House National Nature Reserve, Westmorland J Anim Ecol 33 27–48

Cherry, H R , & R.V Dowell 1979 Predators of citrus blackfly (Hom. Aleyrodidae) Entomophaga 24 385–391

Chiu, S C , K C Lo, C C Chen, C C Chen, & C F Chen 1985 Biological control of citrus pests in Taiwan. Special Publication, No 19, TARI pp 1–8

Chiu, S C , Y I Chu & Y H. Lung 1974 The life history and some bionomic notes on a spider, *Oedothora insecticeps* Boes et. St (Micryphantidae: Araneae) Plant Prot Bull (Taiwan) 16 153–161

Chiverton, P A. 1986 Predator density manipulation and its effects on populations of *Rhopalosiphum padi* (Homoptera Aphididae) in spring barley Ann Appl Biol. 109 49–60

Choi, S Y , H R Lee, & J K Ryu 1978 Effects of carbofuran root–zone placement on the spider populations in the paddy fields. Korean J Plant. Prot. 17 99–103

Chu, Y , & C. Okuma. 1970 Preliminary survey on the spider fauna of the paddy fields in Taiwan. Mushi (Fukuoka) 44 65–88

Chu, Y I., C C Ho, & B J Chen 1975 Relative toxicity of some insecticides to green rice leafhopper, brown planthopper and their predator *Lycosa pseudoannulata.* Plant Prot. Bull (Taiwan) 17 424–430

Chu, Y I , D S Lin, & T. Mu 1976a. The effect of BPMC and Unden on the predation of *Lycosa* spider (*Lycosa pseudoannulata*) Plant Prot Bull (Taiwan) 18 42–57

Chu, Y.I , D S Lin, & T Mu. 1976b Relative toxicity of 9 pesticides against rice insect pests and their predators. Plant Prot. Bull (Taiwan) 18 369–376

Chu, Y L, D S Lin, & T Mu. 1976c. The effect of Padan, Ofunack, Sumithion on the feeding amount of *Lycosa pseudoannulata* (Boes et Str) Plant Prot. Bull. (Taiwan) 18.377–390

Chu, Y L, & C T Wang. 1972 Studies on the *Lycosa pseudoannulata* (Boes et Str) (Araneae Lycosidae) (I) External features and habits. Plant Prot Bull (Taiwan) 14 169–174

Chu, Y I, & C T Wang 1973 Studies on the feeding habits of *Lycosa pseudoannulata* (Boes et Str) Plant Prot Bull (Taiwan) 15 13–20

Clark, E W, & P A. Glick. 1961 Some predators and scavengers feeding upon pink bollworm moths. J Econ. Entomol 54 815–816

Clarke, R.D, & P R. Grant 1968 An experimental study of the role of spiders as predators in forest litter community Part 1 Ecology 49 1152–1154

Clausen, C.P 1927 The citrus insects of Japan USDA Tech. Bull (Washington) 15 9–10

Clausen, C P 1931 Two citrus leafminers of the Far East. USDA. Tech Bull (Washington) 252 1–13

Comstock, J H. 1948 The Spider Book Comstock Publishing Associates Inc, Cornell University Press. Ithaca, New York

Corrigan, J E, & R G Bennet 1987 Predation by *Chiracanthium mildei* (Araneae Clubionidae) on larval *Phyllonorycter blancardella* (Lepidoptera, Gracillariidae) in a greenhouse J Arachnology 15 132–134

Costello, M.J, & K.M Daane 1995 Spider (Araneae) species composition and seasonal abundance in San Joaquin Valley grape vineyards Environ Entomol 24 823–831

Cottenie, P, & R.D Clercq 1977 Study of the arachnofauna in fields of winter wheat. Parasitica 33 138–147

Culin, J D, & R.W Rust. 1980 Comparison of the ground surface and foliage dwelling spider communities in a soybean habitat Environ. Entomol 9 577–582

Culin, J D, & K V Yeargan 1983 Comparative study of spider communities in alfalfa and soybean ecosystems. Foliage-dwelling spiders. Ann. Entomol Soc Am 76 825–831

Czajka, M, & C Kania. 1976 Spiders (Aranei) in potato agrococenosis in Pawlowice Wielkie near Wroclaw in 1971–1974 Pol Pismo Entomol 46 623–629

Czajka, M , & M Goos. 1976 The spiders (Araneae) of sugar beet fields in Pawlowice Wielkie near Wroclaw Pol Pismo Entomol 46 179–185

De Bach, P , & D Rosen 1990 Biological Control by Natural Enemies Cambridge University Press, Cambridge 440 p

De Clercq, R. 1979 On the influence of the soil fauna on the aphid population in winter wheat Int Symposium on "Integrated Control in Agriculture and Forestry," Vienna, 8–12 October Summaries of main lectures and discussion papers 79p

Dean, D A , W L Sterling, & N V Horner 1982. Spiders in eastern Texas cotton fields J Arachnol. 13 111–120

Deitz, L.L , J W Duyn, J R Bradley, R.L Rabb, W M Brooks, & R.E Stinner 1976 A guide to the identification and biology of soybean arthropods in North Carolina. Technical Bulletin, North Carolina, Agricultural Experiment Station 238 264

Dalchev, K., & A. Kajak 1974 Analysis of a sheep pasture ecosystem in the Pienny Mountains (the Carpathians) XIV Effect of pasture management on the number and biomass of spiders (Araneae) in two climatic regions (the Pienny and the Stroina Gora Mountains) Ekol Pol 22 693–710

Dicke M , & M DeJong. 1988 Prey preference of the phytoseiid mite *Typhlodromus pyri* 2. Electrophoresis Diet Analysis Exp Appl Acar 4 15–25

Dietrich, W , & R Götze 1974 Oekologische Untersuchungen der Spinnen-fauna einer Agrobiozönose (unter besonderer Berücksichtigung der Araneae) Unpublizierte Diplomarbeit, Sektion Biowissenschaften Fachbereich Zoologie, Martin-Luther Universität Halle

Dingler M 1935 Die Tierwelt des Spargelfeldes Z Ang Entomol 21 291–327

Dippenaar-Schoeman, A.S 1976 An ecological study of a spider population in strawberries with special reference to the role of *Pardosa crassipalpis* Purcell (Araneae Lycosidae) in the control of *Tetranychus cinnabarinus* (Boisduval)
M Sc thesis, Rand Afrikaans University 119 p

Dippenaar-Schoeman, A.S 1979a Spider communities in strawberry beds: seasonal changes in numbers and species composition Phytophylactica 11 1–4

Dippenaar-Schoeman, A.S 1979b A simple technique for studying feeding behaviour of spiders on mites. Bull Brit Arachnol Soc 4 349

Doane, J F., & C.D Dondale 1979 Seasonal captures of spiders (Araneae) in a wheat field and its grassy borders in central Saskatchewan Can Entomol 111 439–445

Dondale, C D 1956 Annotated list of spiders (Araneae) from apple trees in Nova Scotia. Can. Entomol 88 697–700

Dondale, C D 1958 Note on population densities of spiders (Araneae) in Nova Scotia in apple orchards Can. Entomol 90 111–113

Dondale, C D 1966 The spider fauna (Araneida) of deciduous orchards in the Australian capital territory Austr J Zool 14 1157–1192.

Dondale, C.D 1971 Spiders of Haasman's field, a mown meadow near Belleville, Ontario Proc. Entomol. Soc. Ontario 101 62–69

Dondale, C D 1977 Life histories and distribution patterns of hunting spiders (Araneae) in an Ontario meadow J Arachnol 4 73–93

Dondale, C D , & M R Binns 1977 Effect of weather factors on spiders (Araneae) in an Ontario meadow Can J Zool 55 1336–1341

Dondale, C.D., B Parent, & D Pitre 1979 A 6–year study of spiders (Araneae) in a Quebec apple orchard Can. Entomol 111.377–380

Dondale, C D , J H. Redner, E-Farrell, R.B Semple, & A.L Turnbull 1970 Wandering of hunting spiders in a meadow Bull Mus Hist Nat (Paris) 41 61–64

Dondale C D , J H. Redner, & R.B Semple 1972 Diel activity periodicities in meadow arthropods Can J Zool 50 1155–1163

Dorris, P.R. 1970 Observations on the impact of certain insecticides on spider populations in a cotton field Proc Ark Acad Sci 24 53–54

Duffey, E 1962 A population study of spiders in limestone grassland J Anim Ecol 31 571–599

Duffey, E. 1974 Comparative sampling methods for grassland spiders. Bull Brit. Arachnol Soc. 3 34–37

Dunn, J A. 1949 The parasites and predators of potato aphids. Bull. Entomol. Res. 40 97–122

Edwards, G B 1996 Insect detection Tri-Ology 35 1

Edwards, R. J 1958. The spider subfamily Clubioninae of the United States, Canada, and Alaska (Araneae Clubionidae) Bull Mus Comp Zool 118 365–434

Ela, R.M. 1955 Four insecticide-fungicide combination sprays in the control of some pests affecting citrus in the Philippines Philipp Agric (Laguna) 39 354–363

Erkilic, L.B , & N Uygun 1997 Studies on the effects of some pesticides on white peach scale, *Pseudaulacaspis pentagona* (Targ Tozz.) (Homoptera Diaspididae) and its side-effects on two common scale insect predators Crop Protection 16 69–72

Everly, R.T 1938 Spiders and insects found associated with sweet corn with notes on the food habits of some species. 1 Arachnida and Coleoptera. Ohio J Sci 8 134–140

Ferguson, H. J , R.M McPherson, & W.A. Allen 1984 Ground- and foliage-dwelling spiders in four soybean cropping systems. Environ Entomol 13 975–980

Fitzpatrick, E.G , H R Cherry, & R.V Dowell 1979 Effects of Florida citrus pest control practices on the citrus blackfly (Homoptera Aleyrodidae) and its associated natural enemies Can. Entomol 111 731–734

Fletcher, T.B 1914 Some south Indian Insects Govt. Pr., Madras 565 p

Fletcher, T B 1920 Life histories of Indian insects Microlepidoptera. Mem. Dept. Agric. India (New Delhi) 6 1-217

Foelix, R. 1982 Biology of Spiders Harvard University Press, Cambridge, MA. 306 p

Foelix, R. F 1996 Biology of Spiders. 2nd Ed Oxford University Press, Oxford

Fox, C J S & C D Dondale. 1972 Annotated list of spiders (Araneae) from hayfields and their margins in Nova Scotia. Can Entomol 104 1911 1915

Fraser, A.M 1982 The role of spiders in checking cereal aphid numbers Ph D dissertation, University of East Anglia.

Galecka, B 1966 The role of predators in the reduction of two species of potato aphids *Aphis nasturtii* Kalt and *A frangulae* Kalt Ekol Pol A. 14 245–274

Gavarra, M R., & R S Raros 1975 Studies on the biology of the predatory wolf spider *Lycosa pseudoannulata* Boes et. Str (Araneae Lycosidae) Philipp Entomol 2 427–444

Goos, M 1973 Influence of aphicides used in sugar–beet plantations on arthropods II Studies on arachnids Arachnoidea Pol Pismo Entomol 43 851–859

Greenstone, M H 1979 Spider feeding behavior optimizes dietary essential amino acid composition. Nature 282 501–503

Gyoutoku, Y., K Murray T Miyata, & T Isoda. 1996 The resistance of the citrus leafminer, *Phyllocnistis citrella* Stanton, to insecticides and a laboratory bioassay method Japan J Appl Entomol. Zool. 40 238–241

Hagstrum, D W, 1970 Laboratory studies on the effect of several insecticides on *Tarentula kochi* J Econ Entomol 63 1844–1847

Hamamura, T 1969 Seasonal fluctuation of spider population in paddy fields Acta Arachnol 22 40–50

Hamamura, T 1971 Ecological studies of *Pirata subpiraticus* (Boes and Strand) (Araneae Lycosidae) I Acta Arachnol 23 11–18

Hamamura, T 1980 Studies on the overwintering of the citrus leafminer, *Phyllocnistis citrella* Stanton (Lepidoptera Lyonetiidae) in Hiroshima. Kaju Shikenjo Hokoku Bull Fruit Tree Res Sta. (Akitsu) Ser E 3 99–112.

Hanifa, A M , & S Palaniswamy 1977 Evaluation of certain insecticides against citrus leafminer *Phyllocnistis citrella*, on acid lime Internatl Symp Citriculture (Bangalore) 34 p

Harrison, J O 1968 Some spiders associated with banana plants in Panama. Ann. Entomol Soc Am 61 878–884

Hashimoto, R. 1974 Some spiders of the paddy field and their seasonal fluctuation Agric. Chem 21 22–26

Hassan, S A. 1994 The effects of pesticides on beneficial organisms activities of the IOBC International working group pp 114–118 In Siconbiol Simposio de Controle Biologico Embrapa/CPACT, Pelotas, RS Gramado, Brasil May 15–20

Haynes, D L., & P Sisojevic 1966 Predatory behavior of *Philodromus rufus* Walckenaer (Araneae Thomisidae) Can Entomol 98 113–133

Hensley, S.D , W H. Long, L R Roddy, W J McCormick, & E J Concienne 1961 Effects of insecticides on the predaceous arthropod fauna of Louisiana sugarcane fields J Econ Entomol 54 146–149

Heong, K. L , G.B Aquino, & A T Barrion 1991 Arthropod community structures of rice ecosystems in the Philippines. Bull. Entomol Res 81 407–416

Heppner, J B 1995 Citrus leafminer (Lepidoptera Gracillariidae) on fruit in Florida. Fla. Entomol 78 183 186

Heppner, J B 1993 Citrus leafminer, *Phyllocnistis citrella*, in Florida (Lepidoptera. Gracillariidae Phyllocnistinae) Trop Lepidoptera 4 49-64

Hirano C., & K. Kiritani 1976 Paddy ecosystem affected by nitrogenous fertilizer and insecticides pp 992 In Science for better environment (Proc. of the Intern. Congr on the Human Environment, Kyoto, 1975) Asahi Evening News, Tokyo

Hokyo, N., M H Lee, & J S Park 1976 Some aspects of population dynamics of rice leafhoppers in Korea Korean J Plant Prot 15 111–126

Holling, C S 1961 Principles of insect predation Annu Rev Entomol 6 163–182

Horner, N V 1972 *Metaphidippus galathea* as a possible biological control agent J Kans Entomol Soc. 45 324–327

Howard, F W , & A.D Oliver 1978 Arthropod populations in permanent pastures treated and untreated for red imported fire ant control Environ Entomol 6 901–903

Howard, F W , & G.B Edwards 1984 Web-building spiders on coconut palms and their prey (Arachnida. Araneae). Fol Entomol Mex 62 81–87

Howell, J O., & R.L Pienkowski 1971 Spider populations in alfalfa, with notes on spider prey and affect of harvest. J Econ Entomol 64 163–168

Hoy, M A., & R. Nguyen. 1994 Classical biological control of citrus leafminer in Florida. Citrus Industry 75 22

Huang, M , & S Li. 1989 The damage and economic threshold of citrus leafminer (Stainton) in citrus. pp 84-89 In Studies on the Integrated Management of Citrus Insect Pests Academic Book and Periodical Press, Beijing (In Chinese and English abstract)

Huang, M Z , & M D Huang. 1989 Study on the spatial pattern of larvae of Citrus leafminer pp 90-95 In Studies on the Integrated Management of Citrus Insect Pests Acad Bk & Periodical Pr , Guangzhou (In Chinese)

Huang, M , D Cheng, S Li, X. Mai, & W Tan 1989 Studies on annual population dynamics and control strategy of the citrus leafminer, *Phyllocnistis citrella* pp 63-75 In The Integrated Management of Citrus Pests Academic Book and Periodical Press (In Chinese)

Huffaker, C.B., P S Messenger, & P De Bach 1971 The natural enemy component in natural control and the theory of biological control pp 16-67 In C B Huffaker (ed) Biological Control Plenum Press, New York.

Huhta, V., & M Raatikainen 1974 Spider communities of leys and winter ceral fields in Finland Ann. Zool Fenn. 11 97–104

Hukusima, S & K Kondo 1962 Further evaluation in the feeding potential of the predaceous insects and spiders in association with aphids harmful to apple and pear growing and the effect of pesticides on predators Japan J Appl Entomol Zool 6.274–280

Hukusima, S 1961 Studies on the insect association in crop field XXI Notes on spiders in apple orchards Japan J Appl Entomol Zool 5 270–272.

Hume, H H 1957 Citrus Fruits Macmillan Company, New York, 444 p

Ikemoto, T 1972 Ecological studies on a field population of the citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera. Phyllocnistidae), with special reference to spatial distribution pattern. Japan J Appl Entomol Zool. (Tokyo), 16 127–138

International Rice Research Institute 1973 Ann Report for 1972. Author, Los Baños, Philippines

International Rice Research Institute. 1974 Ann. Report for 1973 Author, Los Baños, Philippines.

International Rice Research Institute. 1975 Ann Report for 1974 Author, Los Baños, Philippines

International Rice Research Institute 1976. Ann Report for 1975 Author, Los Baños, Philippines

International Rice Research Institute. 1973 Ann Report for 1976 Author, Los Baños, Philippines

International Rice Research Institute 1978 Ann Report for 1977 Author, Los Baños, Philippines

International Rice Research Institute. 1985 Ann Report for 1984 Author, Los Baños, Philippines

Ito, I, T Shibata, K. Shimohara, & K Kawachi 1982 Characteristics of fenvalarate in controlling the citrus leafminer *Phyllocnistis citrella* Stainton (Lepidoptera Gracillariidae) Appl Entomol Zool 17 284–286

Ito, J, K Miyashita, & K. Sekiguchi 1962 Studies on the predators of rice drop insect pests, using the insecticidal check method Japan J Ecol 12 1–11

Jacas, J A., A. Garrido, C Margaix, J Forner, A. Alcaide, & J A. Pina 1997 Screening of different citrus rootstocks and citrus-related species for resistance to *Phyllocnistis citrella* (Lepidoptera Gracillariidae) Crop Protection 16 701–705

Jacas, J A., & J.E. Peña. 1999 Calling behavior of two different field populations of *Phyllocnistis citrella* Stainton effect of age and photoperiod Entomol Exp Et Appl (in Press).

Jackson, R R., & M S Tarsitano 1993 Responses of jumping spiders to motionless prey Bull Brit Arachnol Soc. 9 105

Johnson, E K , J H Young, D R. Molnar, & R. Morrison 1976 Effects of three insect control schemes on populations of cotton insects and spiders, fruit damage, and yield of Wesburn 70 cotton. Environ. Entomol 5 508–510

Kagan, M 1943 The araneida found on cotton in central Texas Ann. Entomol Soc. Am. 36:257–258

Kaihotsu, K 1979 Spiders and their seasonal fluctuation in a citrus orchard and a tea field in Mie Prefecture. Atypus 74 29–39

Kajak, A. 1960 Changes in the abundance of spiders in several meadows Ekol Pol A 8 199–228

Kajak, A. 1962 Comparison of spider fauna in artifical and natural meadows Ekol Pol A 10 1–20

Kajak, A. 1971 Productivity investigation of two types of meadows in the Vistula Valley IX. Production and consumption of field layer spiders. Ekol Pol A 19 197–211

Kajak, A 1978 The effect of fertilizers on number and biomass of spiders in a meadow Symp Zool Soc London 42 125–129

Kajak, A. 1980 Do the changes caused in spider communities by the application of fertilizers advance with time? Proc. Int Arachnol Congr , 8th Vienna, pp 115–119

Kajak, A., L Andrzejewska, & Z Wójcik 1968 The role of spiders in the decrease of damages caused by Acridoidea on meadows – experimental investigation Ekol Pol A 16 755–764

Kajak, A., A. Breymeyer, & J Petal 1971 Productivity investigation of two types of meadows in the Vistula Valley Predatory arthropods Ekol Pol. A 19.223–233

Kajak, A., & H Jakubcyzk 1975 Experimental studies on spider predation Proc. Int Arachnol Congr , 6th, Amsterdam, 1974, pp 82–85

Kakiya, N., & K Kiritani 1976 Comparison of sampling techniques to estimate the population density of *Lycosa pseudoannulata* in a paddy field. Japan J Appl Entomol Zool 20 21–25

Kalode, M B 1976 Brown planthopper in rice and its control Indian Farming 27 3–5

Kang, J , & K, Kiritani 1978 Winter mortality of the green rice leafhopper (*Nephotettix cincticeps* Uhler) caused by predation Japan J Appl Entomol Zool 22 243–249

Kaston, B.J 1978 How to Know the Spiders 3rd ed Wm. C Brown, Dubuque, Iowa. 272 p

Kawahara, S 1975 Population dynamics of micryphantid spiders in the paddy field. Bull Kochi Inst Agr & Forest Sci , No. 7 53–64

Kawahara, S., & K Kiritani 1975 Survival and egg sac formation rates of adult females of *Lycosa pseudoannulata* (Boes and Str) (Araneae, Lycosidae) in the paddy field. Appl Entomol Zool. 10 232–234

Kawahara, S , K Kiritani, & T Sasaba 1971 The selective activity of rice-pest insecticides against the green rice leafhopper and spiders Botyo-Kagaku 36 121–128

Kawahara, S , K Kiritani, T Sasaba, F Nakasuji, & C Okuma 1969 Seasonal changes in abundance and the faunal composition of spiders in the paddy field with special reference to their relation to the seasonal prevalence of the green rice leafhopper, *Nephotettix cincticeps* Uhler Proc. Assoc Pl Prot Sikoku 4 33–44

Kayashima, I 1960 Studies on spiders as natural enemies of crop pests (I) Daily activities of spiders in the cabbage fields, establish–effectiveness of spiders against against crop pests. The Science Bull Faculty of Agric Kyushu Univ 18 1–24

Kayashima, I 1967 Study on spiders (particularly referring to grass spiders) to prey upon fall-web worms (*Hyphantria cunea* Drury) Acta Arachnol 21 1–30

Kayashima, I 1972. Study on grass spiders as a predator to *Hyphantria cunea* Drury (Experiment on effectiveness as a predator of *Agelena opulenta* L. Koch) Acta Arachnol 24 60–72

Kenmore, P.E. F D Cariño, C A. Perez, V A. Dyck, & A.P Gutierrez. 1984 Population regulation of the rice brown planthopper (*Nilaparvata lugens* Stal) within rice fields in the Philippines. J Plant Prot. Trop 1 19–37

Kiritani, K. 1973. Systems approach for management of rice pests. pp. 591–598. In J.S. Packer and D. White (Eds). Proc. XV Int. Congr. Entomol. Washington, D.C., August 19–27, 1976, Entomol. Soc. Am., Md.

Kiritani, K. 1979. Pest management in rice. Ann. Rev. Entomol. 24:279–312.

Kiritani, K., & N. Kakiya. 1975. An analysis of the predator-prey system in the paddy field. Res. Popul. Ecol. 17:29–38.

Kiritani, K., & S. Kawahara. 1973. Food chain toxicity of granular formulations of insecticides to a predator, *Lycosa pseudoannulata* of *Nephotettix cincticeps*. Botyo–Kagaku 38:69–75.

Kiritani, K., S. Kawahara, T. Sasaba, & F. Nakasuji. 1972. Quantitative evaluation of predation by spiders on the green rice leafhopper, *Nephotettix cincticeps* Uhler, by a sight-count method. Res. Popul. Ecol. 13:187–200.

Kirn, B. 1978. Untersuchung der epigäischen Spinnenfauna (Araneae) in Rebkulturen. Staatsexamensarbeit in Zoologie, Universität Freiburg i. Br.

Klun, J.A. 1975. Insect sex pheromones: intraspecific variability of *Ostrinia nubilalis* in North America and Europe. Environ. Entomol. 4:891–894.

Knapp, J.L. 1995. 1996 Florida Citrus Pest Management Guide. Fla. Coop. Ext. Serv., Institute of Food and Agricultural Sciences. University of Florida, Gainesville, Florida.

Knapp, J., L.G. Albrigo, H.W. Browning, R.C. Bullock, J. Heppner, D.G. Hall, M.A. Hoy, R. Nguyen, J.E. Peña, & P. Stansly. 1995. Citrus leafminer, *Phyllocnistis citrella* Stainton. Current Status in Florida–1995. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida.

Knapp, J., J. Peña, P. Stansly, J. Heppner, & Y. Yang. 1993. Citrus leafminer, a new pest of citrus in Florida. Citrus Industry 74:42–43, 62.

Kobayashi, S. 1975. The effect of *Drosophila* release on the spider population in a paddy field. Appl. Entomol. Zool. 10:268–274.

Kobayashi, S. 1977. Change in population density of spiders in paddy field during winter. Acta Arachnol. 27:247–251.

Kobayashi, S., & H. Shibata. 1973. Seasonal changes in population density of spiders in paddy fields, with reference to the ecological control of the rice insect pests. Japan J. Appl. Entomol. Zool. 17:193–202.

Kohno, M , & S Makino 1969 Studies on the control of citrus leafminer by insecticidal dusts. Proc. Kyushu Assoc Plant Prot 15 160–163

Koyama, J 1972 Spiders in paddy fields in Akita Prefecture. Ann Plant Prot. North Japan 23 127

Koyama, J 1975 Studies on the diminution of insecticide application to the rice stemborer, *Chilo suppressalis* Walker III The effect of insecticide application on the density of larvae of the rice stem borer and spiders. Japan J Appl. Entomol Zool 19 125–132

Koyama, J 1976 The effects of low concentration of chlorphenamidine on the rice stemborer, *Chilo suppresalis* Walker, and on spiders The Rice Entomology Newsletter, IRRI 4 29–30

Kraemer, P 1961 Einfluss einiger Arthropoden auf Raubmilben (Acari) Z. Ang Zool 48 257–311

Krebs, C.J 1989 Ecological Methodology Harper Collins Publishers, New York, NY 654 p

Kurums, Y 1983 Spiders inhabiting the colonial webs of the fall webworm, *Hyphantria cunea* Drury (Lepidoptera Arctiidae) Appl Entomol Zool 18 81–89

Kurisaka, M 1928 On the life history of citrus leafminer *Phyllocnistis saligna*, Zell , and the relation between this miner and citrus canker, *Pseudomonas citri* Hasse. Insect World (Gifu) 24 39–44 (In Japanese)

Land, M F 1985 The morphology and optics of spider eyes pp 53–78 In. F G Barth ed Neurobiology of arachnids. Springer-Verlag, Berlin

Legner, E F , & E R Oatman 1964 Spiders on apple in Wisconsin and their abundance in a natural and two artifical environments. Can. Entomol. 96 1202–1207

Leigh, T F , & R.E. Hunter 1969 Predaceous spiders in California cotton Calif. Agric 23 4–5

Leius, K. 1967 Influence of wild flowers on parasitism of tent caterpillar and codling moth Can Entomol 99 444

Lesar, C D , & J D Unzicker 1978a Soybean spiders species composition, population densities and vertical distribution Il Nat Hist Surv Biological Notes 107 14

Lesar, C D , & J D Unzicker 1978b Life history, habits, and prey preferences of *Tetragnatha laboriosa* (Araneae Tetragnathidae) Environ Entomol 7 879–884

Levi, H.W., L.R. Levi, and H.S. Zim. 1968. Spiders and their Kin. Golden Press, New York. 160 p.

Liu, S.K., & R.G. Zeng. 1981. Larval stages of the citrus leafminer (*Phyllocnistis citrella* Stainton). J. S. China Agric. Univ. (Kuangchou) 2:51–57 (In Chinese).

Liu, X. 1990. Citrus leafminer. In: The Chinese Encyclopedia of Agriculture, Entomology Volume. Agricultural Publishing House. Beijing. pp. 120–121.

Lo, K.C., & S.C. Chiu. 1988. The illustrations of citrus insect pests and their natural enemies in Taiwan. Taiwan Agric. Res. Inst., Taichung. 75 p.

Lockley, T.C., J.W. Smith, W.P. Scott, & C.R. Parencia. 1979. Population fluctuation of two groups of spiders from selected cotton fields in Panola and Pontotoc Counties, Mississippi, 1977. Southwest. Entomol. 4:20–24.

Löfstedt, C., J. Löfqvist, M. Appelgren, & J.N.C. Van der Pers. 1986. Sex pheromone dialects in European turnip moths *Agrotis segetum*. Oikos 46:250–257.

Lucero, R.M., & R.S. Raros. 1975. Toxicity of Carbofuran and Gamma–BHC to the spiderlings of the wolf spider, *Lycosa pseudoannulata* Boes. Et Str. (Araneae: Lycosidae). Philipp. Entomol. 3:69–75.

Luczak, J. 1974. Ecological groups of spiders of potato and rye fields. Bull. Akad. Pol. Sci., Cl. II. Ser. Sci. Biol. 22:377–383.

Luczak, J. 1975. Spider communities of the crop–fields. Pol. Ecol. Stud. 1:93–110.

Luczak, J. 1976. A decrease of arachnofauna in agrocenoses as a result of agrotechnical treatments. pp. 99–103. In: H. Sandner (ed.), Entomologia a ochrona Vrodowiska. PWN, Warszawa.

Luczak, J. 1979. Spiders in agrocoenoses. Pol. Ecol. Stud. 5:151–200.

Müller, H.J., R. Bährmann, W. Heinrich, R. Marstaller, G. Schäller, & W. Witsack. 1978. Zur Strukturanalyse der epigäischen Arthropodenfauna einer Rasen–Katena durch Kescherfänge. Zool. Jb. Syst. 105:131–184.

MacLellan, C.R. 1973. Natural enemies of the light brown apple moth, *Epiphyas postvittana*, in the Australian Capital Territory. Can. Entomol. 105:681–700.

Malausa, J.C., S. Quilici, & P. Brun. 1996. Status and first studies on the citrus leafminer in France: Azur Coast, Corsica and Reunion Island, p. 88. In: M.A. Hoy (ed.). Proceedings, International Meeting: Managing the Citrus Leafminer, 22–25 April 1996, Orlando, Florida. University of Florida, Gainesville, Florida.

Malo, S.E., & C.W. Campbell. 1991. The tahiti lime. Fact Sheet FC–8, Fruit Crops Department, Fla. Coop. Ext. Serv., University of Florida, Gainesville.

Mansour, F. 1987a. Effect of pesticides on spiders occurring on apple and citrus in Israel. Phytoparasitica 15:43–50.

Mansour, F. 1987b. Spiders in sprayed and unsprayed cotton fields in Israel, their interactions with cotton pests and their importance as predators of the Egyptian cotton leaf worm, *Spodoptera littoralis*. Phytoparasitica 15:31–41.

Mansour, F. 1988. Spiders as biocontrol agents in a citrus grove and their susceptibility to different pesticides. pp. 1215–1221. In: R. Goren & K. Mendel (eds.), Proc. Sixth Int. Citrus Congr. March 6–11, 1988. Tel-Aviv, Israel.

Mansour, F., D. Rosen, & A. Shulov. 1980a. Functional response of the spider *Chiracanthium mildei* (Arachnida: Clubionidae) to prey density. Entomophaga 25:313–316.

Mansour, F., D. Rosen, & A. Shulov. 1980b. A survey of spider populations (Araneae) in sprayed and unsprayed apple orchards. Acta Oecol. Applic. 1:189–197.

Mansour, F., D. Rosen, & A. Shulov. 1981. Disturbing effect of a spider on larval aggregations of *Spodoptera littoralis*. Entomol. Exp. Appl. 29:234–237.

Mansour, F., D. Rosen, A. Shulov, & H.N. Plaut. 1980c. Evaluation of spiders as biological control agents of *Spodoptera littoralis* larvae on apple in Israel. Acta Oecol. Applic. 1:225–232.

Mansour, F., J.W. Ross, G.B. Edwards, W.H. Whitcomb, & D.B. Richman. 1982. Spiders of Florida citrus groves. Fla. Entomol. 65: 514–522.

Mansour, F., & W.H. Whitcomb. 1986. The spiders of a citrus grove in Israel and their role as biocontrol agents of *Ceroplastes floridensis* (Homoptera: Coccidae). Entomophaga 31:269–276.

Margolis J., & C.W. Wrigley. 1975. Improvement of pore gradient electrophoresis by increasing the degree of crosslinking at high acrylamide concentrations. J. Chromatogr. 106:204–209.

Maurer, R. 1974. Die Vielfalt der Käfer und Spinnenfauna des Weisenbodens im Einflussbereich von Verkehrsimmissionen. Oecologia (Berlin) 14:327–351.

Maurer, R. 1975. Epigäische Spinnen der Nordschweiz I. Mitt. Schweiz. Entomol. Ges. 48:357–376.

McCaffrey, J.P., & R.L. Horsburgh 1978 Laboratory feeding studies with selected spiders (Arachnida: Araneae) from Virginia apple orchards. J New York Entomol Soc 86 308

McCaffrey, J.P., & R.L. Horsburgh. 1980 The spider fauna of the apple trees in central Virginia. Environ Entomol 9.247–252

McDaniel, S.G., & W.L. Sterling 1979 Predator determination and efficiency on *Heliothis virescens* eggs in cotton using ^{32}P Environ. Entomol. 8 1083–1087

McIver, J.D., & D.L. Belnavis 1986 A list of the spiders of peppermint in Western and Central Oregon Proc. Entomol Soc Wash 88 595–598

Miyai, S., K. Kiritani & T Sasaba. 1978 An empirical model of *Lycosa* – hoppers interaction system in the paddy field Protection Ecology 1 9–21

Mizell, R.F III, & D.E. Schiffhauer 1990 Effects of pesticides on pecan aphid predators, *Chrysoperla rufilabris* (Neuroptera Chrysopidae), *Hippodamia convergens*, *Cycloneda sanguinea* (L.), *Olla v nigrum* (Coleoptera. Coccinellidae), and *Aphelinus perpallidus* (Hymenoptera Encyrtidae) J Econ Entomol. 83 1806–1812

Mo, Y.S., P.J. Lu, & S.R. Huang. 1981 A good result in control of citrus leafminer with pyrethroids Guangdong Nongye Kexue 6 47–48

Morakote, R., & P. Nanta. 1996. Current status of biological control on citrus leafminer, *Phyllocnistis citrella* Stainton and Asian citrus psyllid, *Diaphorina citri* Kuwayama in Thailand In Proceedings of semi–annual workshop of integrated pest management in selected fruit trees. (in Press)

Moulder, B.C., & D.E. Reichle. 1972 Significance of spider predation in the energy dynamics of forest–floor arthropod communities Ecol Monogr 42 473–498

Muma, M.H. 1973 Comparison of ground-surface spiders in four central Florida ecosystems Fla. Entomol 56 173–196

Muma, M.H 1975 Spiders in Florida citrus groves Fla. Entomol 58 83–90

Muniappan, R., & H.L. Chada 1970a Biological control of the greenbug by the spider, *Phidippus audax*. J Econ Entomol 63 1712

Muniappan, R. & H.L. Chada. 1970b Biology of the crab spider *Misumenops celer* Ann Entomol Soc Am 63 1718–1722

Murdoch, W.W 1971 The developmental response of predators to changes in prey density Ecology 52 132–137

Murray, R.A., & M.G Solomon 1978 A rapid technique for analyzing diets of invertebrate predators by electrophoresis. Ann Appl Biol 90 7–10

Mysore, J.S , & D.W Pritchett 1986 Survey of spiders occurring in cotton fields in Quachita Parish, Louisiana Proc Louisiana Acad Sci 49 53–56

Nagalingam, B , & P Savithri 1983 Studies on the chemical control of citrus leafminer *Phyllocnistus citrella* Stainton (Gracillariidae: Lepidoptera) Pestology 4 21–24

Nakasuji, F 1976 Factors responsible for the change in the pest status of the tobacco cutworm *Spodoptera litura* (Lepidoptera Noctuidae) Physiol Ecol Japan 17 527–533

Negm, A.A., & S.D Hensley 1969 A list of spiders in sugarcane fields in Louisiana. Proc Louisiana Acad Sci 32 50–52

Nohara, K., & K Yasumatsu 1965 Observation on the activity of spiders and effect of insecticides on their populations in the citrus groves around Hagi City, Honshu, Japan. The Science Bull Faculty of Agric Kyushu Univ 23 151–167

Nordlund, D.A., D.C. Vacek, & D.N Ferro 1991 Predation of Colorado potato beetle (Coleoptera Chrysomelidae) eggs and larvae by *Chrysoperla rufilabris* (Neuroptera. Chrysopidae) larvae in the laboratory and field cages J Entomol Sci 26 443–449

Nyffeler, M. 1982 Field Studies on the Ecological Role of the Spiders as Insect Predators in Agroecosystems (Abandoned Grassland, Meadows, and Cereal Fields) Ph.D dissertation Swiss Federal Institute of Technology, aku-Fotodruck, Zurich. 174 p

Nyffeler, M , & G Benz. 1979a Zur ökologischen Bedeutung der Spinnen der Vegetationsschicht von Getreide- und Rapsfeldern bei Zürich (Schweiz) Z Ang. Entomol 87 348–376

Nyffeler, M , & G Benz 1979b Nischenberlappung bezüglich der raum- and Nahrungskomponenten bei Krabbenspinnen (Araneae Thomisidae) und Wolfspinnen (Araneae: Lycosidae) in Mähwiesen Revue Suisse Zool 86 855–865

Nyffeler, M., & G Benz. 1980 The role of spiders as insect predators in cereal fields near Zürich (Switzerland Proc. Int Arachnol Congr 8th Vienna, pp 127–131

Nyffeler, M , & G Benz. 1981 Oekologische Bedeutung der Spinnen als Insektenprädatoren in Wiesen und Getreidefeldern. Mitt Dtsch. Ges. Allg. Angew Entomol. 3 33–35

Oei-Dharma, H.P 1969 Use of pesticides and control of economic pests and diseases in Indonesia. Leiden E J Brill 199 p

Okuma, C 1968 Preliminary survey on the spider fauna of the paddy fields in Thailand. Mushi (Fukuoka) 42 89–118

Okuma, C 1973 Spiders of orchards Shokubutsu–bōeki 27 207–212

Okuma, C 1974 Aeronautic spiders caught by the trap net above paddy fields Sci. Bull Fac Agr , Kyushu Univ 29 79–85

Okuma, C 1977 Study on the seasonal fluctuation of the spiders in the paddy field ecosystem at Tsuya, Fukuoka City Sci Bull Fac. Agr , Kyushu Univ 31 133–144.

Okuma, C , M H Lee, & N Hokyo 1978 Fauna of spiders in a paddy field in Suweon, Korea. Esakia 11 81–88

Okuma, C , & T Wongsiri 1973 Second report on the spider fauna of the paddy fields in Thailand. Mushi (Fukuoka) 47 1–17

Ooi, P A.C , & B M. Shepard 1994 Predators and parasitoids of rice insect pests pp 585-612 In E A. Heinrichs (ed) Biology and Management of Rice Insects Wiley Eastern Limited London

Ortu, S 1996 Field observations on sexual attraction of *Phyllocnistis citrella* Stainton (7Z, 11Z)-7,11-hexadecadienal Proc XX International Congress of Entomology Firenze, Italy, Aug. 25–31, 496 p

Park, K.Y , & J S Kim 1973 Survey on the spider fauna and their seasonal fluctuation in paddy fields of Taegu, Korea. Korean J Plant Prot. 12 125–130

Park, W H , J Namkoong, & H K. Kim 1973 Spider fauna of the mulberry fields at Suwon, Korea. Korean J Plant Prot 12 57–62.

Park, W H , J Namkoong, & H K Kim 1974 A list of spiders collected in the rice paddy of Milyang. Korean J Plant Prot. 13 24

Pandey, N D , & Y D Pandey 1964 Bionomics of *Phyllocnistis citrella* Stt. (Lepidoptera Gracillariidae) Indian J Entomol 26 417–423

Parker, S P 1980 Encyclopedia of Environmental Science (2nd ed) McGraw Hill Book Company, New York. 858 p

Peck, W B , & W H Whitcomb 1970 Studies on the biology of a spider *Chiracanthium inclusum* (Hentz) Agr Ext. Stn. Bull 753 1–76

Peck, W.B., & W.H. Whitcomb. 1978. The phenology and populations of ground surface, cursorial spiders in a forest and a pasture in the south central United States. Symp. Zool. Soc. London 42:131–138.

Peña, A., H. Arn, H.R. Buser, S. Rauscher, F. Bigler, R. Brunetti, S. Maini, & M. Tóth. 1988. Sex pheromone of European corn borer, *Ostrinia nubilalis*: polymorphism in various laboratory and field strains. J. Chem. Ecol. 14:1359–1366.

Peña, J.E., & R. Duncan. 1993. Control of the citrus leafminer in south Florida. Proc. Fla. State. Hort. Soc. 106:47–51.

Peña, J.E., R. Duncan, & H. Browning. 1996. Seasonal abundance of *Phyllocnistis citrella* (Lepidoptera: Gracillariidae) and its parasitoids in south Florida citrus. Environ. Entomol. 25:698–702.

Pfrimmer, T.R. 1964. Populations of certain insects and spiders on cotton plants following insecticide applications. J. Econ. Entomol. 57:640–644.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13:131–144.

Pieters, E.P., & W.L. Sterling. 1974. Aggregation indices of cotton arthropods in Texas. Environ. Entomol. 3:598–600.

Pimentel, D. 1961. Competition and species-per-genus structure of communities. Ann. Entomol. Soc. Am. 54:323–333.

Plagens, M.J. 1985. The corn field spider community: composition, structure, development, and function. Ph.D. dissertation. University of Florida, Gainesville, 206 p.

Plagens, M.J. 1986. Aerial dispersal of spiders (Araneae) in a Florida cornfield ecosystem. Environ. Entomol. 15:1225–1233.

Platnick, N. 1974. The spider family Anyphaenidae in America North of Mexico. Bull. Mus. Comp. Zool. 146:205–266.

Polenec, A. 1968. Untersuchungen der terrestrischen Arachnidenfauna im slowenischen Karstgebirge. Die Weiden innerhalb der *Seslerio autumnalis*- Ostryetum-Aociation bei Divaca. Biol. Vestn. 16:77–84.

Poole, R.W. 1974. An introduction to quantitative ecology. McGraw-Hill Book Co., New York, 532 p.

Provencher, L, D Coderre, & C D Dondale. 1988 Spiders (Araneae) in corn fields in Quebec Can. Entomol. 120 97–100

Putman, W L. 1967 Prevalence of spiders and their importance as predators in Ontario peach orchards Can Entomol 99 160–170

Putman, W L, & D H.C Herne 1966 The role of predators and other biotic agents in regulating the population density of phytophagous mites in Ontario peach orchards Can Entomol 98 808–821

Quaintance, A.L., & C T Brues. 1905 The cotton bollworm U S Dept Agr Bur Entomol Bull 50 1–15

Raatikainen, M, & V Huhta. 1968 On the spider fauna of Finnish oat field. Ann Zool Fenn. 5 254–261

Radke, S G, & H.G Kandalkar 1988 Chemical control of citrus leafminer P.K.V Res J 12 123–125

Radke, S G, & A.Y Thakare. 1989 Chemical control citrus leafminer P.K.V Res. J 13 44–47

Raju, N B T, K R Reddy, S V Rao, K. Lakshminarayana, & B.H Rao 1977 Efficiency of different insecticides for the control of citrus leafminer in A.P Internatl. Symp Citriculture, Bangalore, pp 1-34

Reddy, K.R.S, P Savitri, & P K Rao 1989 Chemical control of citrus leafminer *Phyllocnistis citrella* St Indian J Entomol 50 468–475

Ren, Y & J Wu 1989 Citrus Pest Control Handbook Jindun Publishing House, Beijing, 154 p (In Chinese)

Richman, D A. 1969 A revision of the genus *Hentzia* (Araneae, Salticidae) J Arachnol 17 285–344

Riechert, S E & L Bishop 1990 Prey control by an assemblage of generalist predators in a garden test system Ecology 71 726–736

Riechert, S E & T Lockley 1984 Spiders as biological control agents. Ann. Rev Entomol 29 299–320

Robinson, M H, & B Robinson 1974 A census web-building spiders in a coffee plantation St Wau, New Guinea, and an assessment of their insecticidal effect. Trop Ecol 15 95–107

Rogers, C E , & N V Horner 1977 Spiders of guar in Texas and Oklahoma Environ Entomol 6 523–524

Room, P M 1979 Parasites and predators of *Heliothis* spp (Lepidoptera Noctuidae) in cotton in the Namoi Valley, New South Wales J Aust Entomol Soc 18 223–228

Root, R.B 1967 The niche exploitation pattern of the blue–gray gnatcatcher Ecol Monogr 37 317–350

Roth, V D 1993 Spider Genera of North America With Keys to Families and Genera and a Guide to Literature American Arachnological Society, Gainesville, FL.

Rovner, J S 1978 Adhesive hairs in spiders behavioral functions and hydraulically mediated movement. Symp Zool Soc. Lond. 42.99

Roy, M., C.O Andrew, & T H. Spreen. 1996 Persian limes in North America Florida Science Source Inc., Lake Alfred FL.

Russell, R.M , J L Robetson, & N E Savin 1977 POLO a new computer program for probit analysis. Bull Entomol Soc. Am 23:209–213

SAS Institute 1989 SAS/STAT user's guide, version 6, third Ed Vol 2 SAS Institute Inc., Cary, NC, 846 p

Sadana, G L , & D Sandhu 1977 Feeding intensity of developmental instars of the spider *Marpissa ludhianaensis* on the fulgorid pest of grapevines Sci and Cult 43 550–551

Sadana, G L , & M Kaur 1974 Spiders and their prey in citrus orchards Proc 61st Indian Congr 63 p

Salinas, G D , & R.S Raros. 1975 Importance of first prey to spiderling survival in *Lycosa* sp (Araneae Lycosidae) Philipp Entomol 3 22–29

Samal, P , & B C Misra. 1975 Spiders the most effective natural enemies of the brown planthopper in rice. Rice Entomol Newsletter 3 31

Sandhu, G S , & R.C Batra. 1978a Incidence of citrus leafminer *Phyllocnistis citrella* injury on different cultivars and rootstocks of citrus in the Punjab Punjab Hort. J (Patiala) 18 92–96

Sandhu G S , & R.C Batra. 1978b Sources of resistance as observed under field infestation against citrus leafminer Sci Cult (Calcutta) 44 122–124

Sasaba, T., & K Kiritani 1974 Simulations of the population changes of *Lycosa* in a paddy field Appl Entomol Zool. 9 273–275

Sasaba, T, K Kiritani, & S Kawahara 1970 Assessment of the predatory ability of spiders for comparative purposes Japan J Entomol Zool. 14 144–146

Sasaba, T, K Kiritani, & S Kawahara 1973a. Food preference of *Lycosa* in paddy fields Bull Koch Inst Agr Forest. Sci 5 61–64

Sasaba, T., K. Kiritani, &T Urabe 1973b A preliminary model to simulate the effect of insecticides on a spider–leafhopper system in the paddy field Res Popul Ecol 15 9–22.

Savory, T H. 1926 British Spiders, Their Haunts and Habits Clarendon Press, Oxford

Saxena, R.C, H.D Justo Jr, & P B Epino 1984 Evaluation and utilization of neem cake against the rice brown planthopper, *Nilaparvata lugens*, J Econ. Entomol 77 502–507

Schaefer, M, & L Haas 1979 Untersuchungen zum Einfluss der Mahd auf die Arthropodenfauna einer Bergwiese Drosera (Oldenburg) 79 17–40

Schaffer, B, J E. Peña, A.M. Colls & A. Hunsberger 1997 Citrus leafminer (Lepidoptera Gracillariidae) in lime. Assessment of leaf damage and effect on photosynthesis Crop Prot. 16 337–343

Schauff, M.E., & J LaSalle 1996 Citrus Leafminer Parasitoid Identification Workshop Identification Manual Workshop in Managing the Citrus Leafminer Orlando, FL, April 23

Schlinger, E I., & E J Dietrick. 1960 Strip–farming alfalfa Calif Agric 14 8–9

Seiler, G J., G Zolnerowich, N V Horner, & C. E Rogers 1987 Spider fauna of selected wild sunflower species sites in the southwest United States. Great Basin Naturalist 47 280–282

Sharma, V K, & P Sarup 1979 Predatory role of spiders in the integrated control of the maize stalk borer, *Chilo partellus* (Swinhoe) J Entomol Res. 3 229–231

Shepard, B M, & W L Sterling. 1972 Effects of early season applications of insecticides on beneficial insects and spiders in cotton. Tex. Agric. Exp Stn Misc Publ No 1045 14 pp

Shewale, B S, D S Ajri, & D.B Kadam. 1987 Evaluation of various insecticides against citrus leafminer (*Phyllocnistis citrella* Stn.) Curr Res Rep, Mahatma Phule Agric Univ 3 30–32.

Shewale, B S , P V Makar, & V U Kharole. 1983 Insecticidal control of citrus leafminer (*Phyllocnistis citrella*) Pestology 5 9–10

Shulov, A. 1938 Observations on citrus spiders Hadar 11 1–6 (In Hebrew)

Singh, G , & G S Sandhu 1976 New records of spiders as predators of maize borer and maize jassid Curr Sci 45 642

Singh, P 1984 Insect diets Historical developments, recent advances, and future prospects. pp 32–44, In E.G King and N C Leppla (Eds.), Advances and Challenges in Insect Rearing. Agricultural Research Service, Southern Region, U S Department of Agriculture, New Orleans, 306 p

Singh, S P , & N S Rao. 1980 Relative susceptibilities of different species/varieties of citrus to leafminer, *Phyllocnistis citrella* Stainton, Proc Internatl Soc. Citricult (Griffith, Austr) 1978 174–177

Singh, S P , N S Rao, K K Kumar, & B S Bhumannavar 1989 Field screening of citrus germplasm against the citrus leafminer, *Phyllocnistis citrella* Stainton Ind J Entomol 50 69-75

Smith, D , G A.C Beattie, & R. Broadley 1997 Citrus Pests and Their Natural Enemies Integrated management in Australia. Queensland Dept. of Primary Industries, Brisbane

Sohi, G S , & G C Verma. 1966 Feeding habits of *Phyllocnistis citrella* Stainton in relation to the anatomical structure of the leaf Ind J Entomol. 27 483–485

Solomon, M G., R A Murray, & L.P S Van Der Geest 1985 Analysis of prey by means of electrophoresis. In W Helle and M. Sabelis (eds.), Spider Mites and Their Control Elsevier Science Publishers, Amsterdam

Sontakay, K R., & R.L. Gupta. 1945 Seasonal incidence of *Phyllocnistis citrella* Stn. The citrus leafminer Indian Farming (New Delhi) 1 106

Sorensen, T 1948 A method of establishing group of equal amplitude in plant society based on similarity of species content K Danske Vidensk. Selsk 5 1–34

Sparks, A.N , J R Ables & R.L Jones. 1982 Notes on the biological control of stemborers in corn, sugarcane, and rice in the People's Republic of China. pp 193–215 In. Biological Control of Pests in China. USDA, Washington, DC

Specht, H B , & C.D Dondale 1960 Spider populations in New Jersey apple orchards J Econ Entomol 53 810–814

Stainton, H.T 1856 Description of three species of Indian micro-lepidoptera. Trans Entomol Soc London 3,301–304

Stam, P. A. D F Clower, J B Graves, & P E. Schilling 1978 Effects of certain herbicides on some insects and spiders found in Louisiana cotton fields. J Econ Entomol 71 477–480

Stark, J D , P C Jepson, & C F George Thomas 1995 The effects of pesticides on spiders from the lab to the landscapes Rev Pestic Toxic 3 83–110

Suzuki, Y , & C Okuma 1975 Spiders inhabiting the cabbage field. Acta Arachnol 26 58–63

Suzuki, Y , & K. Kiritani 1974 Reproduction of *Lycosa pseudoannulata* (Boesenberg and Strand) (Araneae Lycosidae) under different feeding conditions Japan J Appl Entomol Zool 18 166–170

Taksdal, S 1973 Spiders (Araneida) collected in strawberry fields Norsk. Entomol Tidsskr 20 58–63

Tan, B , & M Huang 1996 Managing the citrus leafminer in China. pp 49–52. In M A. Hoy (ed). Proceedings, International Meeting Managing the Citrus Leafminer, 22–25 April 1996, Orlando Florida. University of Florida, Gainesville, FL

Tanaka, H 1973 Ecological studies of spiders in paddy fields in Kinki (I) Studies on the life cycle of spiders, *Oedothorax insecticeps* Boes et Str and *Enoplognatha japonica* Boes et Str Acta Arachnol 25 10–15

Tanaka, H 1975 Ecological studies of spiders in paddy fields in Kinki (II) Studies on the seasonal fluctuations of the two spiders, *Oedothorax insecticeps* Boes et Str and *Enoplognatha japonica* Boes. et Str Acta Arachnol 26 15–57

Tanaka, T , & T Hamamura. 1968 Population density of spiders in paddy field during winter Bull. College of Agr Utsunomiya Univ 7 73–79

Taylor, R.M., & W A. Foster 1996 Spider nectarivory Amer Entomol 82–86

Temerak, S A. 1981 Nützliche und schädliche Insekten als Beute der Netzspinne *Dictyna* sp (Arachnida, Dictynidae) auf Granatapfelbäumen in Aegypten Anz. Schädlingskde Pflanzenschutz, Umweltschutz 54 90–93

Terada, T 1977 Studies on spider fauna in a tea field (part 1) Year round change of numbers of spiders and their name list from Nara Prefecture Atypus 69 16–20

Terada, T , K. Yoshimura, & M Imanishi 1978 Studies on a spider fauna in a tea field (part III) Comparative studies on spider fauna of a tea field and the adjacent forests Atypus 72:25–30

Thaler, K J Ausserlechner, & F Mungenast 1977 Vergleichende Fallenfänge von Spinnen und Käfern auf Acker– und Grünlandparzellen bei Innsbruck, Oesterreich Pedobiologia (Jena) 17 389–399

Thaler, K , I, De Zordo, E Meyer, H Schatz, & H. Troger 1978 Arthropoden auf Almflächen im raum Badgastein (Zentralalpen, Salzburg, Oesterreich) veröff. d Oesterr Mab–Hochgebirgsprogr Hohe Tauern Bd 2 96–233

Tongyuan, D , X Jinjun, W Zeshua, & K Fanlei 1989 7Z,Z11-hexadecadienal sex attractant of *Phyllocnistis wampella* Liu et Zeng Kunchong Zhishi 31 47–149

Tothill, J D , T H C Taylor, & R W Paine 1930 The coconut palm moth in Fiji Imp Bur Entomol., London

Toyoda, K., & S Yoshimura. 1966 A study on the natural enemies of insect pests in paddy field 1 Effect of insecticide upon the spiders in paddy field Kyushu Agric Res 28 122–124

Turnbull, A.L 1973 Ecology of the true spiders (Araneomorphae). Ann Rev Entomol 18 305–348

Turnipseed, S G., J W Todd, & W V Campbell 1975 Field activity of selected foliar insecticides against Geocorids, Nabids, and spiders on soybeans. J Georgia Entomol Soc. 10 272–277

Uetz, G W , J Bischoff, & J Rover 1992 Survivorship of wolf spiders (Lycosidae) reared on different diets. J Arachnol. 20.207–221

Ujiye, T 1990 Studies on the utilization of a sex attractant of the citrus leafminer moth, *Phyllocnistis citrella* Stanton (Lepidoptera Phyllocnistidae) I Analysis of seasonal population trends and some behavioral characteristics of the male moths by the use of synthetic sex attaractant traps in the filed Bull Fruit Tree Res Stn 18 19–46

Ujiye, T , K. Kamijo & R Morakote. 1996 Species composition of parasitoids and rate of parasitism of the citrus leafminer (CLM), *Phyllocnistis citrella* Stanton (Lepidoptera Gracillariidae) in central and northern Thailand, with a key to parasitoids of CLM collected from Japan, Taiwan, and Thailand Bull Fruit Tree Res. Stn 29 79–106

Valand, V M , J R Patel, & N C Patel 1992 Bioefficacy of insecticides against citrus leafminer, *Phyllocnistis citrella* Stainton, on Kagzi lime Indian J Plant Prot 20 212–214

Van Der Geest, L P S , & W P J Overmeer 1985 Experiences with polyacrylamide gradient gel electrophoresis for the detection of gut contents of phytoseiid mites Meded Fac Landbouww Rijksuniv Gent 50 469–471

Van Hook, R I 1971 Energy and nutrient dynamics of spider and orthopteran populations in a grassland ecosystem. Ecol. Monogr 41 1–26

Vekateswarlu, C , & S Ramapandu 1992 Compatibility of fungicides and bactericide with insecticides in the control of citrus canker and leafminer in acidlime. Indian J Plant Prot 20 27–31

Verma, G C , & G S Sohi 1967 Studies on the chemical control of citrus leafminer *Phyllocnistis citrella* Stainton (Gracillariidae Lepidoptera) J Res Punjab Agric Univ (Ludhiana) 4 227–232

Verma, R R 1989 Studies on the tolerance species and varieties of *Citrus* to the citrus leafminer, *Phyllocnistis citrella* Stainton Agric. Sci Digest (Karnal) 9 31–33

Vickerman, G P , & K D Sunderland 1975 Arthropods in cereal crops Nocturnal activity, vertical distribution and aphid predation J Appl Ecol 12 755–766

Vilbaste, A 1965 Suveaspekti ämblikefaunast kultuurniitudel (Über den Sommeraspekt der Spinnenfauna auf den Kulturwiesen.) Eesti NSV Teaduste Akad Toimetised (Biol) 14:329–337

Villanueva-Jimenez, J A 1998 Development of an integrated pest management program for the citrus leafminer, (Lepidoptera Gracillariidae) in Florida Nurseries Ph D dissertation University of Florida, Gainesville, Florida 133 p

Villanueva-Jimenez, J A., & M.A. Hoy 1997 Current practices in Florida nurseries for managing the citrus leafminer Citrus Industry 78 80–85

Vivekanandan, P , & T G Naganathan 1983 Efficacy of insecticides in the control of citrus leafminer (*Phyllocnistis citrella*) Pesticides 17 22–23

Vogelei, A & R Greissl 1989 Survival strategies of the crab spider *Thomisus onustus* Walckenaer 1806 (Chelicerata, Arachnida, Thomisidae) Oecologia (Berl) 80 513–515

Weismann, R 1955 Untersuchungen an den Prädatoren der Baumwollschadinsekten in Aegypten im Jahr 1951/52 Acta Tropica 12:222–239

Wheeler, A G 1973 Studies on the arthropod fauna of alfalfa. V Spiders (Araneida) Can. Entomol 105 425–432

Whitcomb, W H 1974 Natural populations of entomophagous arthropods and their effect on the agroecosystem. pp 150–169 In F G Maxwell, and F A Harris (eds), Proc Summer Inst Biol Control Plant Insects and Diseases. University Press of Mississippi Jackson

Whitcomb, W H, & K Bell 1964 Predaceous insects, spiders, and mites of Arkansas cotton fields Bull Ark Univ 690 1–83

Whitcomb, W H., & M Tadic 1963 Araneida as predators of the fall webworm. J Kans Entomol Soc. 36 186–190

Whitcomb W H. 1975 Ecological role of cursorial spiders in agroecosystems Proc Int. Arachnol Congr, 6th, Amsterdam, 1974, 95 p

Whitcomb, W H 1980 Sampling spiders in soybean fields pp 544–558 In M Kogan, & D.Z Herzog (eds) Sampling Methods in Soybean Entomology Springer, New York.

Whitcomb, W H., H. Exline, & M Hite. 1963a. Comparison of spider populations of ground stratum in Arkansas pasture and adjacent cultivated field Proc Ark. Acad Sci 17 6

Whitcomb, W.H., H Exline, & R.C Hunter 1963b Spiders of the Arkansas cotton field Ann. Entomol Soc. Am. 56 653–660

Wilson, C G 1991 Notes on *Phyllocnistis citrella* Stainton (Lepidoptera. Phyllocnistidae) attacking four citrus varieties in Darwin J Aust Entomol Soc. 30 77–78

Wisniewska, J, & R. Prokopy 1993 Spiders that feed on leafhoppers and leafminer Fruit Notes 58 1–2.

Wisniewska, J, Y Yang, & R. Prokopy 1993 Spiders in second–level and first–level apple IPM blocks. Fruit Notes 58 20–23

Wolcott, G N 1937 An animal census of two pastures and a meadow in northern New York. Ecol Monogr 7 1–90

Woods, M W & R C Harrel 1976 Spider populations of a southeast Texas rice field. Southw Nat 21 37–48

Wu, K C, & C C Tao 1977 Comparative study of spraying and painting insecticides against citrus leafminer, *Phyllocnistis citrella* (Phyllocnistidae Lepidoptera) J Agric Res. China (Taipei) 26 158–168

Wyss, E, U Niggli, & W Nentwig 1995 The impact of spiders on aphid populations in a strip-managed apple orchard J Appl. Entomol 119 473–478

Yaginuma, T 1965 Spides found in the paddy field Plant Protection 19 361–368

Yamamoto, E. 1968 Studies on the biology and control of the citrus leafminer *Phyllocnistis citrella* Stainton I On the biology Proc Assoc Plant Prot Kyushu (Fukuoka) 14 47–50 (In Japanese)

Yamamoto, E 1969 Studies on the biology and control of the citrus leafminer *Phyllocnistis citrella* Stainton 2. On the ecology Proc Assoc. Plant Prot. Kyushu (Fukuoka) 15 158–160 (In Japanese)

Yamamoto E. 1971 Studies on the biology and control of the citrus leafminer *Phyllocnistis citrella* Stainton. 3 On the development Proc. Assoc. Plant Prot Kyushu (Fukuoka) 17 64–65 (In Japanese)

Yamamoto, E. 1972 Studies on the biology and control of the citrus leafminer, *Phyllocnistis citrella* Stainton, 4 Insecticidal control. Proc. Assoc Plant Prot. Kyushu (Fukuoka) 18 61–63 (In Japanese)

Yamanaka, K., F Nakasuji, & F Kiritani 1973 Life tables of the tobacco cutworm *Spodoptera litoralis* and the evaluation of effectiveness of natural enemies Jpn. J Appl Entomol Zool 16 205–214

Yamano, T 1977 Seasonal fluctuation of population density of spiders in paddy field in Kyoto City Acta Arachnol 27 253–260

Yeargan, K V 1975a. Prey and periodicity of *Pardosa ramulosa* (McCook) in alfalfa. Environ Entomol 4 137–141

Yeargan, K V 1975b Factors influencing the aerial dispersal of spiders (Arachnida Araneidae) J Kans Entomol Soc. 48 403–408

Yeargan, K V, & W R. Cothran. 1974a An escape barrier for improved suction sampling of *Pardosa ramulosa* (McCook) and *Nabis* spp populations in alfalfa Environ Entomol 3 189–191

Yeargan, K V, & W R Cothran 1974b Population studies of *Pardosa ramulosa* (McCook) and other common spiders in alfalfa Environ Entomol 3 989–993

Yeargan, K.V , & C.D Dondale. 1974 The spider fauna of alfalfa fields in northern California. Ann. Entomol Soc. Am 67 681–682

Zhang, A., C O'Leary, & W Quarles 1994 Chinese IPM for citrus leafminer Update. IPM Practitioner 16 10–13

Zhao, J.C. 1989 Preservation and application of lacewings. Wuchang Univ Press, Wuchang Hubei Province 244 p

BIOGRAPHICAL SKETCH

Divina Medina Amalin was born 28 June 1959 in Laguna, Philippines She was raised in Santa Rosa, Laguna, where she completed her primary and secondary education. She obtained the Bachelor of Science (B S) degree with Entomology as her major at the University of the Philippines, Los Baños (UPLB) Her research in B S program was on the "Taxonomy of Jumping Spiders" While she was in college, she worked at the International Rice Research Institute (IRRI) as a student assistant. After earning her Bachelor of Science degree, she worked as a research assistant in the Department of Life Sciences at UPLB In this department, she was involved in spider taxonomy and in *Drosophila* biosystematic research In 1984, she began to pursue her Master of Science (M S) degree in Entomology at UPLB and earned it in 1988 Her thesis research in M S program was on the "Biology and Systematics of Philippine Spiders Causing Araneidism" Directly after graduation, she was hired as an assistant professor in the Institute of Biological Science at UPLB In 1990, she decided to join the International Potato Center (CIP) regional office in the Philippines. Her affiliation with CIP was a unique learning experience in dealing with applied research. She was involved in the on-farm research of the Integrated Pest Management in potato and sweet potato Her direct involvement with the potato and sweet potato farmers and researchers in Southeast Asia (i e Indonesia, Philippines, Thailand, and Vietnam) in solving pest problems was very challenging, sometimes frustrating, but most of the time rewarding.

In 1993, she was awarded a teaching fellowship in the Department of Plant and Soil Science at the University of Vermont, while in the University of Vermont, she was involved in maple and apple entomological research. However, she really wanted to enrich her knowledge in entomological research on tropical and subtropical crops, which would be applicable to the Philippines and other Southeast Asian countries. Therefore, she decided to apply for another graduate program at the University of Florida. In 1995, she was accepted in the University Florida and awarded a graduate research assistant from the Tropical Research and Education Center. Her research has focused on Integrated Pest Management (IPM) of citrus leafminer with biological control as the major component. Her research experience in tropical entomology broadened by exposure to the different entomological research problems in South Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jorge E. Peña, Chair
Professor of Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Robert McSorley, Cochair
Professor of Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Harold Browning

Harold Browning
Professor of Entomology and Nematology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jonathan Reiskind
Associate Professor of Zoology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jonathan Crane

Jonathan Crane
Associate Professor of Horticultural Science

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy

May 1999

Dean, College of Agriculture

Dean, Graduate School